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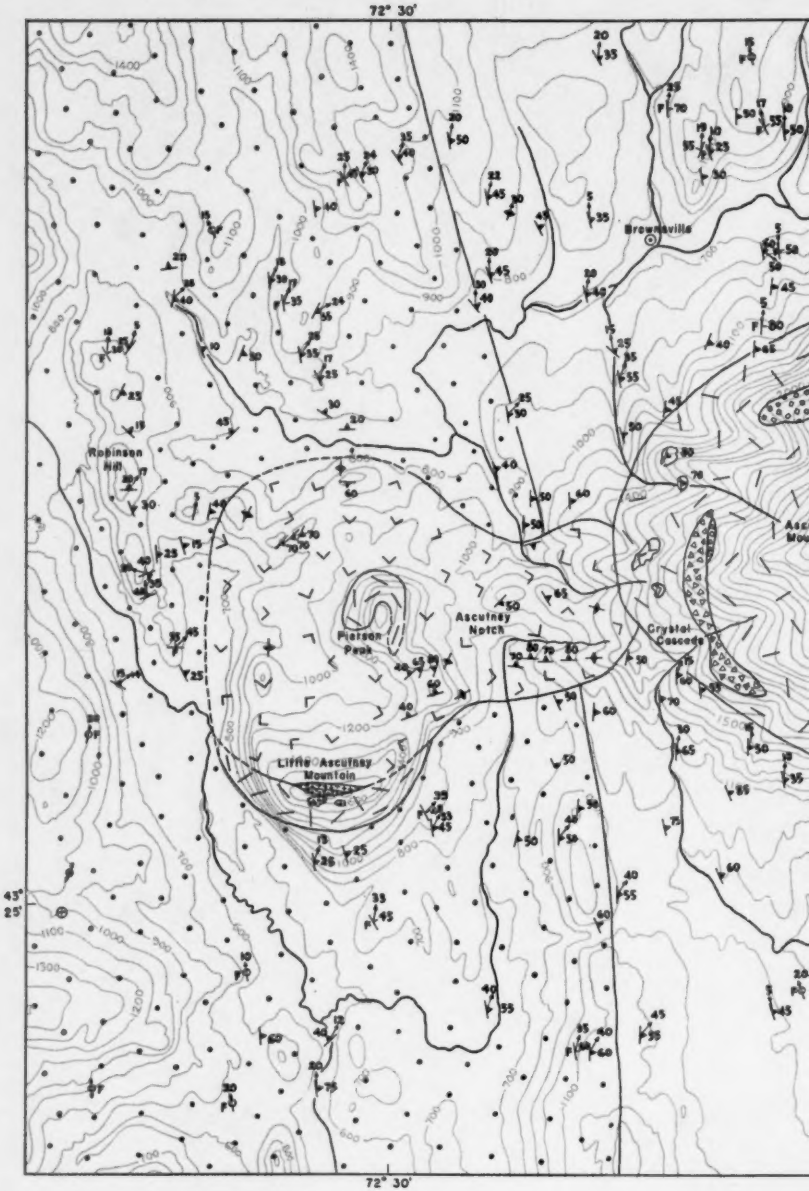
72° 30'
Brownsville
Robinson Hill
Pierson Peak
Ascutney Notch
Crystal Cascade
Little Ascutney Mountain
43° 25'
72° 30'

GEOLOGIC

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72° 25'
Windsor
Ascutney
Connecticut River
N
43° 25'
42° 25'
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Hornblende granite
Biotite syenite
Paisanite
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Strike of vertical foliation or schistosity
Horizontal foliation
Foliation or schistosity with linear element
Vertical foliation or schistosity with linear element
Horizontal foliation or schistosity with horizontal linear element
Foliation or schistosity with horizontal linear element
Foliation or schistosity with two linear elements
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Linear element alone
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Strike and dip of axial plane of fold with direction and value of plunge of fold
Direction and value of plunge of fold with vertical axial plane
Fold with horizontal axis and vertical axial plane
Fold with horizontal axis and dipping axial plane
Village
0
1
2
scale of miles
Contour interval = 100 feet
Topography redrawn from Claremont, N.H.-Vt. and Ludlow, Vt., quadrangles of the U.S. Geological Survey

VERMONT

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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CAULDRON SUBSIDENCE AT ASCUTNEY MOUNTAIN, VERMONT

BY RANDOLPH W. CHAPMAN AND CARLETON A. CHAPMAN

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ABSTRACT

In 1903 Daly published his classic report on Ascutney Mountain, Vermont, in which he concluded that this igneous complex was emplaced by piecemeal stoping. Since that time, however, many studies of igneous bodies have been made. Accordingly, it was deemed advisable to restudy Ascutney Mountain to see what light new information might shed on the method of intrusion. Three theories were found worthy of special consideration: forceful injection, piecemeal stoping, and cauldron subsidence.

Forceful injection will not satisfactorily explain the complex for several reasons: (1) The inequidimensional bodies of the complex have their longer axes athwart the regional structure. (2) The strike and dip of the country rock have not been disturbed. (3) The folds and linear features in the country rock are regional and plunge consistently to the north at low angles.

The authors believe that cauldron subsidence (ring-fracture stoping) will best explain the intrusion. Cauldron subsidence is suggested by: (1) The roughly elliptical outline of the main syenite stock of the complex; (2) the slender, arcuate screen of volcanic rocks on the west side of Ascutney Mountain; (3) the crescent-shaped intrusion of Little Ascutney Mountain; and (4) the progressive, easterly shift of centers of successively younger intrusions.

INTRODUCTION

Ascutney Mountain, Vermont, is classic in the science of geology for it was there that Daly (1903, p. 90-113) first developed the theory of magmatic stoping. To explain the intrusion of the igneous complex, he pictured the rising magma making way for itself by engulfing blocks of the country rock disrupted from the roof and walls of the magma chamber. Daly awarded the credit for this theory to earlier workers, but it was he who finally elaborated and developed it. The concept was eagerly adopted by students of petrology the world over, and has become one of the most widely accepted explanations for the emplacement of large igneous bodies.

At the time of Daly's study of Ascutney Mountain comparatively little was known about the geology of northern New England. Since that time, however, many igneous bodies have been mapped there and their petrography and mechanism of intrusion studied. Careful, detailed work has also been done on analogous intrusive bodies in other parts of the world, and new theories of intrusive mechanism have been advanced. Research by members of the Cloos school, for instance, has emphasized the importance of forceful injection, even in the case of large magma bodies. On the other hand, studies in Scotland, as well as in the mountainous region of central New Hampshire, show that in many instances, igneous rocks have been emplaced by a process known as cauldron subsidence. Accordingly, it was deemed advisable to restudy Ascutney Mountain to see what light new observations might shed on the geology of this famous complex.

The field work was done during parts of the summers of 1937 and 1938 and took approximately 8 weeks. Photostatic copies of the Claremont

(New Hampshire-Vermont) and Ludlow (Vermont) quadrangles, enlarged three times, were used as base maps.

The writers wish to express their sincere thanks to Professor Marland P. Billings of Harvard University for his generous assistance in the field work and in the writing of the manuscript. They are especially indebted to Professor R. A. Daly of Harvard University whose valuable comments and criticism of the manuscript have greatly facilitated the preparation of this report. Mr. Frederick C. Kruger, also of Harvard University, assisted the writers during several weeks in the field. The field expenses and the cost of thin sections and maps were financed by a grant from the Shaler Memorial Fund of Harvard University.

DESCRIPTIVE GEOLOGY

GENERAL RELATIONS

The complex of igneous rocks at Ascutney Mountain has invaded highly-folded schists and gneiss. The igneous rocks form a comagmatic series which began with extrusions of flows, tuffs, and breccias followed by intrusions of gabbro, diorite, syenite, and granite. The intrusive phases form large stocks and dikes, whereas the extrusive types occur as screens and xenoliths.

The geologic map of Ascutney Mountain (Pl. 1), prepared by the writers, agrees essentially with Daly's (1903, Pl. 7) and differs only in certain details. The shape of the stock of Conway biotite granite is much more regular on the writers' map than it is on Daly's. Moreover, the boundaries of the various rock units are located somewhat differently on the two maps. The writers have also delineated certain small rock bodies which were not mapped by Daly.

At the time of Daly's study, no topographic map of Ascutney Mountain was available. Later, when one was prepared, the geological data were plotted thereon. Unfortunately, the topography on this early map was somewhat exaggerated and certain valleys were mapped deeper than they actually are. This is the reason that Daly showed geologic contacts bending upstream instead of cutting directly across, as they actually do. In spite of this difficulty, together with that presented by the dense, almost continuous cover of forest on the main mountain, his map is accurate enough to show general relations. It fails, however, to indicate some features, among which the presence of inclusions of extrusive rock in the main stock is particularly important.

The geologic map, as prepared by the writers, together with the topography of the Ascutney Mountain area, is shown in Plate 1. The topography (100-foot contours only) is reproduced from the Ludlow

(Vermont) and Claremont (New Hampshire-Vermont) topographic sheets recently mapped by the United States Geological Survey.

DESCRIPTION OF ROCK BODIES

General statement.—It is not the purpose of this paper to describe the detailed petrography of the rocks at Ascutney Mountain. This has already been done in such an admirable way by Daly that repetition is unnecessary. A brief petrographic description will be given, however, of those volcanic rocks which were not mapped by Daly. On the present occasion the writers are interested primarily in the mechanism by which the rocks of Ascutney Mountain were emplaced. Accordingly, the structural features of the rock bodies will be emphasized because they have an important bearing on the mode of intrusion.

Schist and gneiss.—The country rocks into which the Ascutney Mountain complex is intrusive consists of two types. In the eastern part of the area is a fine, dark schist (called phyllite by Daly) which bounds the Ascutney intrusion on the north, east, and south. This rock consists mainly of quartz and sericite with subordinate amounts of feldspar and chlorite. The schist was undoubtedly a sediment for it is thinly bedded. Intercalated with it are layers of impure limestone, 2 or 3 inches thick, which near the intrusive masses have been altered to lime-silicate bands. The schist has a well-developed foliation generally parallel to the stratification.

West of the schist is a medium- to coarse-grained, gray gneiss. This rock is typically a biotite-muscovite gneiss, but locally contains epidote, scapolite, or garnet. Associated with the gneiss are thin bands of hornblende schist, limestone, and coarse marble. The gneiss is commonly well-banded; locally, as on the northern end of Robinson Hill, these bands show extremely intricate folds.

At present neither the age nor correlation of the schist or gneiss is known, although the problem may be solved by further field work in the surrounding region.

The schist and gneiss have been extremely contorted and recrystallized by regional metamorphism, developing a foliation which strikes north-south and dips east rather steeply. Exceptionally, as on Robinson Hill, the strikes are east-west. In some places, within a few feet of the contact of the main syenite stock, the schistosity departs somewhat from the regional trend, but for the most part it has been unaffected by the intrusion.

Superimposed on the regional schistosity and large folds are smaller folds and crinkles which plunge consistently to the north at low angles

(Pl. 1). These vary in wave length from 2 millimeters to several centimeters and have an amplitude of about one-half their wave-length. As the reader will notice, the orientation and degree of plunge of these crinkles is essentially the same on all sides of the intrusion. Locally, a second and steeper set of crinkles is found, but in all cases where the age relations of the two sets are clear, the steeper set is the older. The foliation planes of the schist and gneiss are commonly characterized by a linear arrangement of muscovite and biotite. Where observed in the presence of the younger crinkles, these linear features are parallel to the axes of the former. Apparently, they resulted from the same movements which produced the crinkles.

Volcanic rocks.—A mass of breccias, tuffs, and dense flows is exposed on the ridge directly west of the top of Ascutney Mountain at an elevation of about 2100 feet. The width of the mass at this point is about 600 feet. The body can be traced northward across the brook and to the crest of the ridge beyond, where it apparently pinches out. It can be traced southward, where it ends abruptly near the southwestern edge of the syenite. Delineation of this mass shows it to be a long, slender, arcuate body more than a mile in length and averaging 400 to 500 feet in width.

On the long ridge which leads due north from the summit of Ascutney Mountain, at an elevation of approximately 2500 feet, is a much smaller mass of similar flows, tuffs, and breccias. This body is lens-shaped with an average diameter of about 600 feet. It lies directly in line with the arcuate trend of the larger mass to the southwest. At an elevation of approximately 1800 feet in the stream which flows due northwest from the top of the mountain, blocks of flow rocks are present as inclusions in the syenite. These are cut by small tongues and stringers of syenite proving that they are older. Although these are too small to map, their presence here, directly in line with the two larger bodies, is extremely significant as will be shown later.

Another small patch of volcanic rocks occurs on the east flank of Ascutney Mountain 100 feet below the summit.

The flow rocks are dark where fresh, but are buff or gray where weathered. They are mainly dense trachytes and rhyolites, some specimens showing phenocrysts of potash feldspar and quartz. Structures in these rocks are invisible to the unaided eye, but the microscope reveals a flow banding in many specimens. The tuffs and breccias are also practically all rhyolitic or trachytic in composition. They are light in color and consist essentially of orthoclase and plagioclase phenocrysts and angular rock fragments set in a dense groundmass of quartz, feldspar,

hornblende, pyroxene, and biotite. Most of the rock fragments range in diameter from one millimeter to 3 or 4 centimeters, and consist of flow rocks which in many cases show trachytic texture. The only place where bedding was seen in the tuffs and breccias was in the small inclusion near the top of Ascutney Mountain.

There are several inclusions of coarse breccia in the syenite on the west side of Little Ascutney Mountain. Two of these are shown in Plate 1. That they are inclusions is proved by the fact that they are penetrated by narrow tongues of the surrounding syenite. As Daly (1903, p. 77-79) pointed out, both the fragments and matrix of this rock are composed of metamorphic material. The fragments, which in some cases are nearly one foot across, consist of schist, gneiss, amphibolite, and milky quartz, types which are common in the formations about Ascutney Mountain. The matrix is a dark, compact, clastic cement of quartz, feldspar, chlorite, biotite, magnetite, and garnet.

Although this peculiar breccia contains no igneous material, the authors believe it to be volcanic in origin, and to represent cemented fragments of the country rock which was perforated by a volcanic vent. The situation is comparable to that in explosion pits or "maars" in which volcanism has simply drilled a vent through the surrounding rock, so that the material blown out consists almost entirely of country rock fragments. Such action may have taken place in the earliest stage of volcanism at Ascutney Mountain.

Gabbro-diorite stock.—The oldest intrusive of the Ascutney Mountain complex is an irregular, stock-like mass lying north and east of Little Ascutney Mountain. Petrographically, it consists of two phases: A coarse, dark gabbro and a lighter diorite. Because these types are so complexly associated in the field it was found impracticable to try to map them separately. However, the diorite phase is the younger since it is commonly found enclosing angular blocks of the gabbro. Briefly, these rocks contain plagioclase, augite, hornblende, and biotite in varying proportions. For a more elaborate discussion of their nature, the reader is referred to Daly's report (1903, p. 38-44).

The gabbro-diorite stock is characterized by a poorly defined planar structure. This is produced either by the platy parallelism of biotite, tabular augite, and plagioclase, or, less commonly, by the orientation of small disc-like inclusions. A study of Plate 1 shows that this planar structure is concentric about two different points in the gabbro-diorite stock, and that it dips inward steeply. Balk (1937, p. 92-94) has pointed out that many basic igneous intrusions possess a funnel-like flow structure which consists of more or less concentric shells dipping inward. The

planar orientation in the gabbro-diorite of Ascutney Mountain suggests the presence of two of these funnel-like structures.

Unfortunately, the contact of the gabbro-diorite with the country rock is not well exposed, and it was impossible, therefore, to determine its attitude directly.

Syenite dike of Little Ascutney Mountain.—Little Ascutney Mountain is formed by a resistant, crescent-shaped dike on the south side of the gabbro-diorite stock. This dike, which is concave to the north, has a maximum width of 600 feet and a total length of one and one-half miles. It consists of a hornblende-biotite syenite similar to one phase of the main syenite stock to the east. Daly mapped the two rocks differently, but on the present map, for the sake of simplicity, both are shown with the same pattern.

The syenite of Little Ascutney Mountain is characterized in places by a vertical, linear orientation not seen in the main syenite stock to the east. This lineation is produced in two ways: First, by the orientation of elongate crystals of hornblende and feldspar, and second, by the drawing out of nodular patches (inclusions), into elongate masses, especially near the edges of the intrusion.

One gains the impression upon observing the extremely steep slope of the southwest side of the mountain that the contacts of the Little Ascutney Mountain dike are steep. This was verified by actual observation at a point on the south side of the mountain where the contact, exposed for a height of 6 feet, is essentially vertical.

The crescentic dike is bordered on the north side by two long, narrow, dike-like intrusives: A coarse biotite syenite, and a fine-grained paisanite. The location and shape of these bodies are indicated on the geologic map (Pl. 1).

Syenite stock of Pierson Peak.—The summit of Pierson Peak is composed of gabbro-diorite. Surrounding this on the east, north, and west is an irregular stock of medium- to coarse-grained syenite which Daly mapped as pulaskite. It is pinkish gray, but is essentially the same as the syenite of the large stock to the east. Accordingly, on the geologic map (Pl. 1) both are indicated by the same symbol. No linear or planar structures were noted in this body, nor were any satisfactory data obtained on the nature or attitude of its walls.

Main syenite stock.—To the east of the gabbro-diorite stock lies a large, elliptical body of massive syenite. Its longer axis trends west-northwest and is over 3 miles in length; its shorter axis is about 2 miles. The rocks composing this body are medium-grained, blue-gray syenites

consisting of perthite, hornblende, biotite, pyroxene, quartz, and accessory minerals. They vary considerably, however, in texture and relative percentage of constituent minerals. Daly (1903, p. 48-68) described four types, but, as he says, the apparent transition of one type into another makes it practically impossible to delimit the individual rock types. For our purposes we can consider the greater part of this mass as a uniform body of syenite, entirely without linear or planar structures, all parts of which were emplaced at about the same time. As shall be seen later, however, it is probable that that part of the stock northwest of the volcanic area is slightly older, although it is no different petrographically from the rest of the mass.

The contact between syenite and country rock is everywhere sharp and distinct. It is not everywhere regular, however, but is characterized in several places by dikes and inclusions. For example, in one or two places along the southern edge of the intrusion, thick, dike-like projections penetrate the schist to a distance of several feet. Several schist inclusions, too small to map, were found near the edge of the syenite just above Crystal Cascade. Some large xenoliths of schist and gabbrodiorite on the western edge of the stock are shown in Plate 1. The boundary between syenite and country rock is essentially vertical. This can be observed at Crystal Cascade on the southwest side of Ascutney Mountain where the little southwesterly flowing stream, which parallels the trail, drops from the resistant syenite to the softer schists below. The actual contact is exposed here for a vertical distance of almost 100 feet. That this vertical attitude is characteristic of the contact elsewhere is shown by the fact that the contact invariably crosses deep gullies without turning up or down the valley.

The syenite stock is characterized in many places by an abundance of more or less rounded basic inclusions. These masses are dark gray, porphyritic, and contain mainly plagioclase, hornblende, augite, and biotite. Daly (1903, p. 64-67), in consonance with the ideas prevailing forty years ago about such bodies, interpreted them as segregations from the syenitic magma. The authors, however, believe them to represent xenoliths [1] of basic rock which have been greatly reworked by the magma.

Hornblende granite stock.—On the north slope of Ascutney Mountain at an elevation of about 2200 feet is a small, elongate stock of fine-grained, light, massive granite. Mineralogically it closely resembles the surrounding syenite except that it contains about 25 per cent of quartz. This body, together with two other smaller bodies of the same rock, is shown in Plate 1.

[1] A paper on this subject is in preparation.

Conway granite stock.—Penetrating the southern part of the main syenite stock is a stock of granite whose average diameter is about one and one-quarter miles. The granite is a medium- to coarse-grained, pink, sub-porphyritic rock composed of pink potash feldspar, smoky quartz, and biotite. This is the Conway granite, so common among the intrusives of central New Hampshire. Orientation of mineral grains is entirely lacking in this rock.

As in the case of the main syenite stock, the contact of the granite body is steep, since it strikes across deep valleys without swinging laterally. At an elevation of 2400 feet on the new road which follows up the ridge on the southeast side of the mountain, the western contact between granite and syenite can be observed in detail. It strikes N. 5° W. and dips 60° W. The eastern contact was found at an elevation of 1000 feet, near the stream which flows east from the center of the granite stock. Its trend is N. 30° W., and its dip 60° NE.

AGE RELATIONS

Before considering the mode of emplacement of the Ascutney Mountain complex, it is necessary to understand the age relations of its many components.

The schist and gneiss are obviously the oldest rocks in the region since they represent the country rock into which the younger rocks were intruded. In many places they are cut by dikes and tongues of the latter.

The volcanic rocks represent the oldest phases of the complex. They are older than the syenite because they occur as inclusions in it and are cut by syenite tongues. They are older than the gabbro-diorite also, because at the summit of the road leading through Ascutney Notch, inclusions of flow rocks were found completely surrounded by gabbro. There is ample evidence that the breccia of Little Ascutney Mountain is likewise older than the gabbro-diorite since elsewhere fragments of it are common as inclusions in the latter.

The gabbro-diorite stock is next in age, and represents the oldest intrusive. That the gabbro is earlier than the diorite is shown by numerous blocks of coarse, black gabbro in the lighter diorite in many places. East of Ascutney Notch, where the gabbro-diorite stock and large syenite stock come into contact, tongues of syenite penetrate the gabbro-diorite. In a similar way the intrusives of Little Ascutney Mountain and Pierson Peak are shown to be younger than the gabbro-diorite.

Although the syenitic rocks are younger than the gabbro-diorite, it is difficult to determine their relative ages. Since the larger bodies are all similar petrographically, however, they were probably all emplaced at

about the same time. Daly (1903, p. 69 and 74) proved that the syenite of Little Ascutney Mountain is younger than the gabbro-diorite and older than the adjacent paisanite dike. We know also that the biotite syenite dike on Little Ascutney Mountain is younger than the gabbro-diorite because off-shoots from it penetrate the latter. The relation of this biotite syenite to the other two syenites here, however, is unknown.

The relative age of the Conway granite stock is best shown on the new road following up the ridge on the southeast side of the mountain. At an elevation of 2400 feet the road crosses the western contact between the syenite and granite. Here the normally coarse-grained granite has taken on a subporphyritic texture due to chilling. Dikes of the subporphyritic rock, together with pegmatites and aplites, cut the older syenite.

The hornblende granite mass on the north side of Ascutney Mountain also cuts the surrounding syenite and is, accordingly, younger. How this compares in age with the Conway granite stock is not known definitely. Nevertheless, the close mineralogical similarity between the syenite and the hornblende granite would suggest that these two are not very different in age, so that the hornblende granite stock is probably older than the Conway granite stock.

The age relations of the Ascutney Mountain rock bodies may be summarized in the following table, the youngest rock being at the top. The age of those bodies marked with an asterisk is uncertain.

Conway granite stock
Hornblende granite stock
Biotite syenite dike *
Paisanite dike *
Main syenite stock
Syenite stock of Pierson Peak
Syenite dike of Little Ascutney Mountain
Gabbro-diorite stock
Volcanic rocks
Schist and gneiss

CORRELATION WITH WHITE MOUNTAIN MAGMA SERIES

All the rock types of the Ascutney Mountain complex can be correlated both petrographically and chronologically with those of the White Mountain magma series so well displayed in northern and central New Hampshire. Both Marland Billings (personal communication) and the writers believe that the flows, tuffs, and breccias are the equivalent of the Moat volcanics which have been described in the North Conway region (Billings, 1928, p. 89-101), the Ossipee Mountains (Kingsley, 1931, p. 154-157), the Belknap Mountains (Modell, 1936, p. 1895-1897), Pleasant Mountain (Jenks, 1934, p. 325-328), etc. Then too, equivalents of the gabbro, diorite, and syenite phases can be found in several places

in New Hampshire (Chapman and Williams, 1935, p. 503-507; Smith, Kingsley, and Quinn, 1939). The coarse, pink, biotite granite, which composes the youngest stock in the area, is the equivalent of the Conway granite which forms abundant stocks in the White Mountains (Chapman and Williams, 1935, p. 503-507).

The age sequence of the rock members of the Ascutney Mountain complex is given in the previous section. This is identical with that established for the White Mountain magma series (Chapman and Williams, 1935, p. 508-509). As will be seen later, these facts have an important bearing on the mode of intrusion at Ascutney Mountain.

The geologic age of the White Mountain magma series is not known exactly. Work in western New Hampshire (Williams and Billings, 1938, p. 1025) indicates, however, that it is probably Mississippian or early Pennsylvanian.

MODE OF INTRUSION

GENERAL STATEMENT

As stated in an earlier section, the restudy of Ascutney Mountain was prompted partly by recent work of members of the Cloos school which has shown that many igneous bodies throughout the world have been emplaced by forceful injection. Balk (1937, p. 88) has intimated that even the Ascutney Mountain complex might have been intruded in the same manner. Since this mechanism is so radically opposed to the hypothesis of piecemeal stoping, the authors felt that further analysis of the field data was desirable in order to determine which explanation is the more satisfactory. They find, however, that the relations at Ascutney Mountain can be explained better by the vertical displacement of large, nearly cylindrical blocks of the country rock.

In the following paragraphs arguments for and against these mechanisms will be considered. In this connection it should be borne in mind that the writers are not attempting to explain how the magma rose into the crust from great depth. On the contrary, they are concerned primarily with the manner in which it has come to occupy its present position near the surface without disrupting the surrounding structures. Because of the nature of the evidence the writers have found it more practical to divide the complex into two parts and to consider separately the mode of intrusion of the compound syenite-granite (eastern) stock and gabbro-diorite (western) stock.

SYENITE-GRANITE STOCK

Forceful injection.—Several facts indicate clearly that the country rock has not been pushed aside by the intrusion of the large composite syenite-

granite stock in the eastern part of the complex. These facts are as follows:

(1) The regional strike of the country rock, as shown in Plate 1, is approximately north-south. The trend of the longer axis of the syenite-granite intrusive, on the other hand, is west-northwest. Other things being equal, one would expect an intrusive, if forcefully injected, to expand parallel to the structure and not across it. For example, the great masses of Bethlehem gneiss in western New Hampshire belong to an older magma series which was forcefully intruded (Billings, 1937, p. 536-538). These are great sheets whose longer axes are parallel to the regional structure.

(2) On referring to Plate 1, it will be seen that the regional trend of the foliation is north-south, and this continues to the edge of the syenite-granite intrusion. Locally, however, the schists near the intrusion are slightly contorted, but only within a few feet of the contact. The foliation dips consistently to the east at steep angles. If the syenite-granite stock were forcibly injected, it is difficult to understand why the surrounding rocks were not affected. In the case of the forcefully intruded Bethlehem gneiss (Billings, 1937, p. 537-538) already mentioned, the foliation of the surrounding schist closely parallels the contacts.

(3) Numerous data were collected on the attitude of folds and linear features, not only close to the intrusion, but also out to a distance of about 2 miles from the contacts. These data are plotted on Plate 1. Except in a few places, such as on Robinson Hill and at the eastern edge of the complex, the folds, crinkles, and linear features plunge consistently to the north at low angles. The direction and amount of plunge are essentially the same close to the intrusion as two miles away. Although detailed mapping was not done more than 2 miles from the limit of the intrusion, reconnaissance work indicates that the attitude of these features is essentially invariable over large areas. Detailed work over hundreds of square miles of New Hampshire and eastern Vermont proves that these folds and linear features are genetically related to the last period of folding and metamorphism. They are older than any of the rocks of the White Mountain magma series, including the Ascutney Mountain complex. The writers believe that these data form one of the most damaging arguments against the hypothesis of forceful injection of the syenite-granite stock. The most significant fact here is that the direction and amount of plunge is the same on all sides of the intrusion. If the intrusion had been injected forcibly, it seems inevitable that these low-plunging, regional features would have been dragged up along the contact. The plunge of the lineation on the north side of the intrusion would thus have been steepened, whereas that on the south side would

have been reversed and would plunge to the south. On the east and west sides of the igneous complex the attitude of the lineation would have been only slightly affected.

It is true that in addition to the horizontal or gently-plunging structural features there is a set of steeply-plunging features. However, in all cases where it is possible to determine their age, the steeply-plunging set is older than the gently-plunging set and, accordingly, has no bearing on the case.

Piecemeal stoping.—Having eliminated forceful injection as a possible means of intrusion, let us now turn to another mechanism, namely that of piecemeal stoping. Although the authors have no definite evidence against this theory, they do not believe that piecemeal stoping, as outlined by Daly in 1903, where numerous, relatively small blocks are stoped down, explains the facts at Ascutney Mountain as well as does another theory to be considered. For example, as will be seen later, it is difficult to explain the arcuate mass of volcanic rocks by piecemeal stoping. Furthermore, a question might be raised as to whether piecemeal stoping would not have proceeded more rapidly parallel to the structural planes rather than across them, thereby producing a body elongated parallel to the regional structure rather than across it as is true in this area. Again, would not piecemeal stoping have produced more irregular and less symmetrical contacts than those found at Ascutney Mountain?

It is realized, of course, that piecemeal stoping, as originally defined, has operated here to a certain degree since blocks of country rock are not uncommon in the intrusives. The authors believe, however, that this process has been accessory, and that some other mechanism can better explain the intrusion of the syenite-granite stock.

Cauldron subsidence.—There remains a third possibility: Space might have been made for the syenite magma and the later granite magma by the displacement of two large cylindrical blocks of country rock which moved either up or down. That the block which made space for the syenite magma moved down is indicated by the masses of volcanic rocks in the syenite. The volcanic rocks, which are the earliest phases of the igneous activity, were extruded upon an ancient surface. It was into this thick series of extrusives that the later syenite-granite stock was intruded (Fig. 1). Since these volcanic rocks do not now occur in the region surrounding the igneous complex, their presence in the syenite suggests that they have dropped down from above.

The outward-dipping contacts of the Conway granite stock, discussed in a previous section, indicate a similar downward sinking of the block

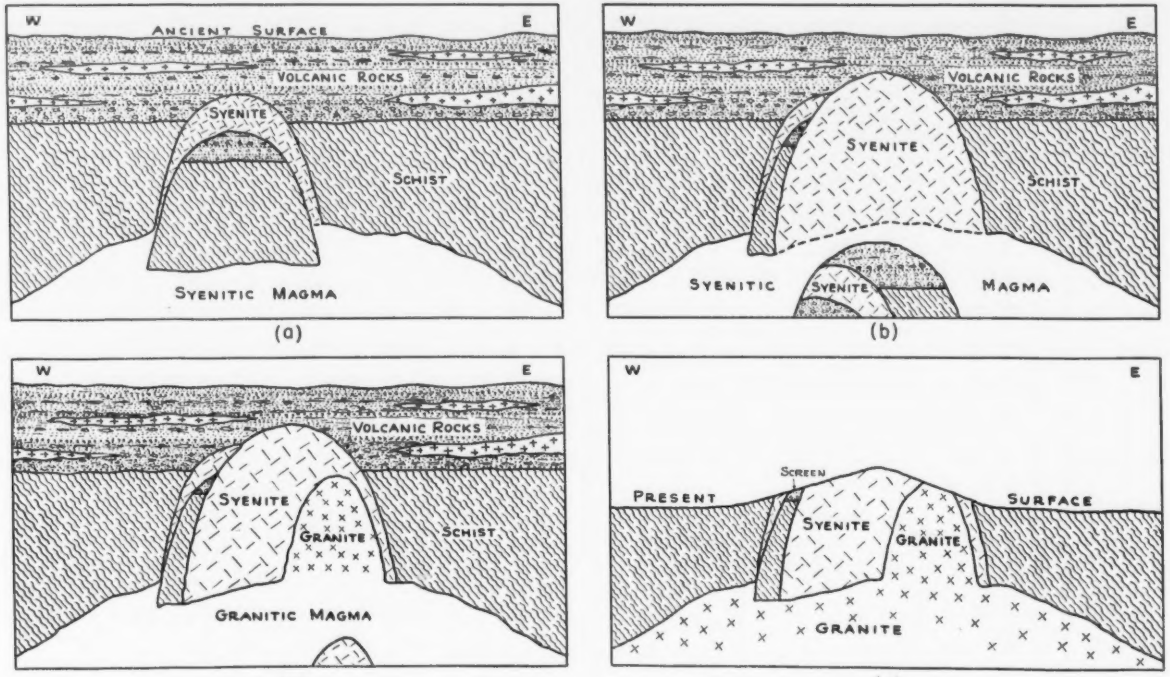

FIGURE 1.—*Evolution of the syenite-granite stock of Ascutney Mountain, Vermont (diagrammatic)*

which made room for the granite stock. It would be mechanically impossible to force a block upward into narrowing walls.

The mechanism suggested here to account for the origin of the syenite-granite stock is that of *cauldron subsidence* or *ring-fracture stoping*, a theory considerably different from that of piecemeal stoping of small blocks. This theory was originally advanced to explain the igneous complex of Glen Coe, Scotland (Clough, Maufe, and Bailey, 1909, p. 11-12). It was later adapted to other Scottish areas such as Mull (Clough, Bailey, and Wright, 1924) and Ardnamurchan (Richey and Thomas, 1930). It is a significant fact that this same mode of intrusion has apparently taken place in several areas in nearby central New Hampshire: Ossipee Mountains (Kingsley, 1931, p. 159-164), Belknap Mountains (Modell, 1936, p. 1922-1931), Percy region (Chapman, 1935, p. 416-421), Franconia region (Williams and Billings, 1938, p. 1038-1042), and North Conway region (Billings, 1928, p. 128-134). At all of these places the rocks involved, like those at Ascutney Mountain, belong to the White Mountain magma series.

The following significant analogies may be drawn between Ascutney Mountain and the Scottish and New Hampshire areas. These analogies are not advanced as definite proofs, but rather as evidence tending to support the hypothesis of cauldron subsidence for the syenite-granite stock.

(1) At Ascutney Mountain the large syenite body is roughly elliptical with the northwest-southeast axis about one mile longer than the northeast-southwest axis. Similarly-shaped bodies are extremely characteristic of areas of cauldron subsidence. For instance, many of the intrusive bodies of the Belknap Mountains (Modell, 1936, Pl. 1) and of the Percy region (Chapman, 1935, Figs. 1, 3) in New Hampshire are elliptical, as are those of Mull (Clough, Bailey, and Wright, 1924, Pl. 6) and Ardnamurchan (Richey and Thomas, 1930, Pl. 5) in Scotland.

(2) Although terminated to the north and south by syenite, the arc-like body of volcanic rocks on the west side of Ascutney Mountain, if projected to the northeast, is found to be in line with the small body of similar rocks due north of the summit of the mountain. The two bodies are separated by nearly one mile of syenite, but it is extremely significant that inclusions of volcanic rocks are not uncommon in the syenite in a zone between the two bodies. These facts strongly suggest a discontinuous screen of volcanic rocks separating a syenite ring dike on the west from a stock-like mass on the east. Such screens are common in all regions of cauldron subsidence. Petrographic study of the syenite, however, revealed no recognizable difference between the two bodies, nor was

any fracture found separating them. Whether the dike is older or younger than the syenite stock to the east cannot be proved, but it appears that the volcanic rocks represent part of a block which dropped down to make space for an outer ring dike (Fig. 1, a). Later another block, bounded by a new fracture, sank to produce the syenite stock to the east (Fig. 1, b).

(3) The crescent-shaped intrusion of Little Ascutney Mountain does not lie within the area of the syenite-granite stock. However, it may rightly be considered here, since the syenite of which it is composed is similar to that of the composite syenite-granite stock, suggesting that both were emplaced at about the same time. The Little Ascutney Mountain intrusion is, without doubt, a ring dike which rose along a circular fracture formed by the sinking of a dome-shaped block. In this connection it should be remembered that ring dikes do not have to be complete rings. This one is merely an arc whose radius is approximately two-thirds of a mile. In its central portion the dike is about 600 feet across, and it pinches out on either end forming a crescent. It is closely analogous to the Cape Horn ring dike of the Percy region (Chapman, 1935, p. 406-407) where cauldron subsidence is known to have taken place.

(4) The progressive, easterly shift of centers of successively younger intrusions, shown at Ascutney Mountain, is characteristic of cauldron subsidence, although it is admitted that this could also take place with other mechanisms. It will be noted that the gabbro-diorite stock, which is the oldest intrusive in the area, lies on the western edge of the complex with its geometrical center near Pierson Peak. The centers of the circles, of which the Little Ascutney Mountain intrusives are arcs, nearly coincide with that of the gabbro-diorite stock. The main syenite stock to the east is younger than the gabbro-diorite stock, its center lying about half a mile east of the summit of Ascutney Mountain. The center of the Conway granite stock, which is the youngest body of all, is located about one and one half miles east-southeast of the summit of Ascutney Mountain. Thus it is evident that with each successively younger intrusion there has been an easterly migration of centers. A similar easterly shift has been noted in the Percy ring dike complex of New Hampshire (Chapman, 1935, p. 416). In the Belknap Mountains of New Hampshire (Modell, 1936, p. 1931) the shift of centers has been toward the northwest. The three centers of intrusion in Ardnamurchan (Richey and Thomas, 1930, Pl. 5) are roughly in line, although the third center lies between the first and second.

GABBRO-DIORITE STOCK

Significant facts.—In considering the origin of the gabbro-diorite stock the following significant facts should be noted.

(1) The shape of the stock suggests either one irregular intrusion, or a large, circular, western body with a smaller, adjacent body to the east.

(2) The gabbro-diorite is characterized by flow structures which dip steeply inward toward two separate centers (Pl. 1), suggesting two vaguely defined funnels.

(3) The attitude of the contact of the stock with the surrounding rocks could not be determined accurately, although the relation between this boundary and the topography of the region suggests that it is steep.

(4) The longer axis of the gabbro-diorite intrusive lies perpendicular to the regional trend of the structures of the country rock.

(5) The attitude of the country rock has not been disturbed by the intrusion. The few erratic strikes and dips on Robinson Hill represent the only significant departures from the regional trend (Pl. 1). Reconnaissance shows, however, that these are related to a major structure some distance northwest of the area and bear no genetic relation to the intrusion.

(6) Most of the folds and linear features in the country rocks are regional and plunge consistently to the north at low angles. The authors believe that those folds and linear features on Robinson Hill which do not conform to the regional trend are also due to a major structure to the northwest.

Unfortunately, information on the structure of the gabbro-diorite stock is incomplete. Accordingly, any theory attempting to explain the origin of this body must be highly speculative. With the above significant facts in mind, let us consider several ways in which the gabbro-diorite stock might have been emplaced.

Forceful injection.—It is difficult to believe that forcing aside of the country rock can satisfactorily explain the intrusion of the gabbro-diorite stock. The objections to this mechanism are those facts discussed in paragraphs 4, 5, and 6 in the preceding section. They are the same arguments used against forceful intrusion of the syenite-granite stock.

Balk (1937, p. 92-94) has pointed out that many gabbroic intrusions are known to have funnel-shaped walls, and almost invariably, where planar flow structures are present, they are nearly parallel to the walls. Although the planar flow structures of the Ascutney Mountain gabbro-diorite are admittedly poor, it is not illogical to assume, with lack of evidence to the contrary, that the walls of this body may dip inward steeply forming a funnel-shaped body.

On this assumption, the stock could be explained by the rising of a funnel-shaped block of country rock pushed upward by the force of the rising magma. This mechanism would not differ greatly from that of

cone sheet intrusion except that the walls of the stock would dip inward much more steeply than those of cone sheets. The funnel arrangement of the planar structures of the gabbro-diorite could then be interpreted as the result of differential flowage of the magma as it rose.

The main objection to this hypothesis is the difficulty of raising the conical block of country rock to a height sufficient to clear the present erosion surface. To illustrate, if the conical fracture formed and the block moved upward slightly, the magma would well into the fracture which would undoubtedly extend to the surface. Continued upward force would fail to raise the block further because the magma would escape to the surface through the funnel-shaped fracture. Nor can further uplift be attributed to the buoyant force of the magma in which the block is now suspended, for Daly (1903, p. 95-96) has shown that the density of a block of this country rock (gneiss) is greater than that of the gabbro magma. Thus, by this mechanism, a funnel-shaped dike would form and not a stock-like body.

Piecemeal stoping.—Here again, the authors have no definite field evidence against the theory of stoping of relatively small blocks to explain the intrusion of the gabbro-diorite stock. Nevertheless, the same objections might be raised as in the case of the syenite-granite stock. It is the authors' opinion that the emplacement of the gabbro-diorite body may be explained better by another theory.

Cauldron subsidence.—If one pictures the walls of the stock as dipping steeply outward, instead of steeply inward, the stock can be explained by cauldron subsidence or the sinking of an irregular block or of two separate conical blocks—one large one and a smaller one to the east. The presence of the Little Ascutney Mountain ring dike supports this view. Although this dike originated much later, it apparently formed as a result of displacement of the gabbro-diorite stock along its southern contact.

The funnel structures of the gabbro-diorite can also be explained on this theory. If we assume that after the gabbro-diorite was nearly crystallized it was subjected to a slight upward thrust from below, the crystal mesh would be sheared in such a way that a funnel-like arrangement of platy minerals and inclusions would be produced. This mechanism does not differ greatly from that of cone sheet intrusion where inwardly-dipping conical fractures are produced by an upward push of the magma from below.

Although the evidence is admittedly poor, the writers believe that cauldron subsidence explains the facts a little more satisfactorily than the other hypotheses mentioned above. Cauldron subsidence not only ac-

counts for the gabbro-diorite stock and its funnel-like flow structures, but it is more closely in harmony with the mechanism by which the syenite-granite stock and the syenite dike of Little Ascutney Mountain appear to have been emplaced.

RELATION OF INTRUSION TO DIFFERENTIATION

In the foregoing sections it was concluded that the syenite-granite stock and the intrusions of Little Ascutney Mountain can be best explained by cauldron subsidence or ring-fracture stoping. The mode of intrusion of the gabbro-diorite stock is not so clear, however, but the evidence suggests that it too may have been emplaced by cauldron subsidence. It is well to consider at this point how the intrusion of these rocks is related to their differentiation. The origin of the White Mountain magma series has been studied in detail by Chapman and Williams (1935). The general scheme of differentiation discussed below has been adapted from this study.

It is the authors' belief that all the rock types at Ascutney Mountain were derived from a parent gabbro magma. This lay in a great reservoir several miles below the surface, where it changed gradually by fractional crystallization and assimilation. The earliest phase of igneous activity consisted of the extrusion of volcanic flows, tuffs, and breccias. Why these early rocks of the White Mountain magma series are rhyolitic and trachytic, however, is a question which so far has not been answered.

The gabbro-diorite stock, the earliest intrusive to form, was emplaced when the magma had changed but little. Due to a decrease in magmatic pressure, or possibly to a weakening of the roof, a dome-shaped block of country rock dropped downward, thereby making room for the gabbro-diorite magma.

After the gabbro-diorite had crystallized, and the magma in the reservoir below had differentiated to a syenitic liquid, settling of the gabbro-diorite stock formed a crescentic gap on the south side of the stock. Rising of the syenitic magma to fill this crevice produced the ring dike of Little Ascutney Mountain. Later settling of the gabbro-diorite resulted in the intrusion of the biotite syenite and paisanite dikes along a fracture between the Little Ascutney Mountain dike and the gabbro-diorite stock. The small Pierson Peak intrusion probably originated at about this time, and may represent the top of a much larger syenite stock below. The geometrical center of all these intrusions is near Pierson Peak.

Before the magma had changed much in composition, the locus of settling shifted toward the east and the large syenite intrusions were formed (Fig. 1). The syenite which lies west of the screen of volcanic rocks is probably part of an older ring dike which has been partly oblit-

erated by the syenite stock east of it. The final shift of centers took place when the differentiating magma had reached the granite stage, and the Conway granite stock was thus formed.

CONCLUSIONS

A restudy of Ascutney Mountain, with the aid of a good base map, shows the geology to be essentially the same as that indicated by Daly. The following conclusions were reached with regard to the origin of the igneous complex.

(1) No evidence was found favoring forceful injection. On the contrary, several facts strongly suggest that the complex cannot be explained satisfactorily by this mechanism.

(2) No serious objections were found to the theory of piecemeal stoping as outlined by Daly in 1903, although it is felt that the major features of the complex can be explained better in another way. It is realized, of course, that piecemeal stoping has operated here, but the authors believe that it has been an accessory process.

(3) All intrusions of the complex can be explained by the sinking of large dome-like blocks (cauldron subsidence). For the syenite and granite bodies the evidence is strongly in favor of such a mechanism. In the case of the gabbro-diorite stock, however, the evidence is meager, but cauldron subsidence is offered as perhaps the best hypothesis.

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RELATIONSHIP BETWEEN FLORAS OF TYPE LANCE AND FORT UNION FORMATIONS

BY ERLING DORF

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ABSTRACT

Despite its controversial nature in connection with Mesozoic-Cenozoic boundary problems, the flora of the Lance formation at its type locality has never been adequately studied or described. During the past two summers collections were made at nine localities in the type Lance Creek area of eastern Wyoming, under joint auspices of the Carnegie Institution of Washington and Princeton University.

Combined with smaller collections from the same region, now in the United States National Museum, the flora at present comprises 74 species, of which eight are apparently new. More than 75 per cent of the species have previously been reported elsewhere. An overwhelming majority are found only in formations now regarded as of Upper Cretaceous age on the basis of both stratigraphy and paleontology.

It is clearly shown that this flora has very little resemblance to the widespread and well-known Fort Union flora. There are only seven species in common between the two floras; one of these species is a long-ranging form, and two of the others are only questionably reported from the Fort Union. As work progresses it is becoming apparent that previously published reports of the similarity between the Lance and Fort Union floras are erroneous and were based mainly on inclusion in the Lance flora of species now known to have come from beds which overlie the true Lance. It is evident that the flora of the nondinosaur-bearing beds which have been generally regarded as upper Lance is of Fort Union aspect and has little in common with the flora of the underlying dinosaur-bearing beds of the true Lance.

INTRODUCTION

PLAN OF WORK

During the past 4 years the writer has been investigating the stratigraphy and paleobotany of the Lance and related formations of the Rocky Mountain region, under the joint auspices of Princeton University and the Carnegie Institution of Washington. The first part of the study, relating to the Medicine Bow formation of southern Wyoming and northwestern Colorado, has been completed (Dorf, 1938). The second part, concerning the Lance formation at its type locality in eastern Wyoming, is nearing completion; 2 weeks of the summer of 1936 and 5 weeks of 1938 were spent in obtaining collections of fossil plants and invertebrates. The present paper deals with only the stratigraphic significance of the fossil plants; the systematic descriptions and the botanical aspects of the flora will be included in a forthcoming comprehensive report.

The writer is indebted to Dr. R. W. Chaney, of the University of California, for valuable suggestions and for criticism of the manuscript; and to his colleagues at Princeton University, Dr. Paul MacClintock and Dr. J. Brookes Knight, for critical reading of the manuscript.

GEOGRAPHICAL AND HISTORICAL SETTING

The type locality of the Lance formation is in eastern Wyoming in the north-central part of Niobrara County (formerly the eastern part of Converse County). It is referred to generally as the Lance Creek area and is the location of the well-known Lance Creek oil field (Hancock, 1921; Emery, 1929). The area lies 25 miles north-northwest of the town of Lusk, Wyoming.

The Lance Creek area was first brought to scientific attention by Hatcher (1893; 1896; 1903), who had collected there a large suite of dinosaur remains subsequently described by Marsh (1907). These included specimens of the diagnostic zone index, *Triceratops*, as well as of *Diceratops* and *Torosaurus*. The terrestrial beds containing the dinosaur remains were originally called the "Ceratops beds" or the "Lance Creek beds" by Marsh and Hatcher. In subsequent reports the beds were referred to also as the "Converse county beds," "Laramie," and "lower Fort Union" (Stanton and Knowlton, 1897; Knowlton, 1909; Stanton, 1909). In view of the inadequacy of any of these names for the unit, Stanton subsequently (1910, p. 172, footnote) renamed the beds as follows:

> "The name Lance formation has recently been adopted by the United States Geological Survey for the 'Ceratops beds' of eastern Wyoming and adjacent areas."

OUTLINE OF THE GEOLOGY

All the plant remains discussed in the present paper were collected from horizons within the limits of the true dinosaur-bearing Lance formation as

originally defined, as shown in Figure 1. Exposures of the formation are to be seen for the most part only in stream banks, although lenticular sandstones occasionally outcrop in low ridges on the otherwise evenly

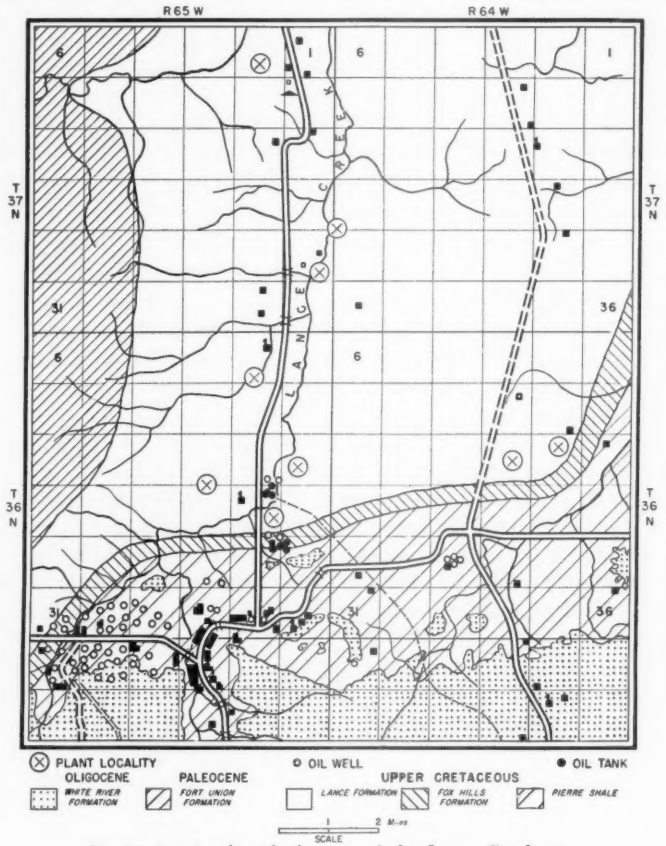

FIGURE 1.—*Areal geologic map of the Lance Creek area*

Showing plant localities in the type Lance formation.

rolling upland surface. Because of the lack of continuous exposures across the strike, the thickness of 1500 to 2200 feet is necessarily only an estimate (Stanton and Knowlton, 1897, p. 131; Stanton, 1910, p. 185).

Plant remains were collected from the following localities:

1. Base of low ridge, near center of SE. ¼ sec. 23, T. 36 N., R. 65 W.
2. South bank of small valley, southwest corner of SE. ¼ sec. 15, T. 36 N., R. 65 W.

3. North bank of small valley, near center of SW. ¼ sec. 13, T. 36 N., R. 65 W.

4. Head of small valley, southeastern portion of SW. ¼ sec. 2, T. 36 N., R. 65 W.

5. Middle of steep cliff along east bank of Lance Creek, center of SE. ¼ sec. 25, T. 37 N., R. 65 W.

6. Base of steep east bank of Lance Creek, southwest corner of SW. ¼ sec. 19, T. 37 N., R. 64 W.

7. Sandstone outcrops in small badlands area, western edge of SE. ¼ sec. 2, T. 37 N., R. 65 W.

8. West bank of deep gully, northwestern corner of SE. ¼ sec. 15, T. 36 N., R. 64 W.

9. North bank of wide gully, western edge of NE. ¼ sec. 14, T. 36 N., R. 64 W.

Knowlton made a collection of plants from four localities in the Lance Creek area in 1896 and shortly thereafter published a tentative list of both Lance and "Fort Union" species, many of which were not named specifically (1896, p. 134, 136). He subsequently published a second tentative list of the species, unfortunately including several of the "Fort Union" forms with those collected from the true Lance (1909, p. 207).

The Lance formation in this region, as elsewhere in eastern Wyoming, eastern Montana, and the western Dakotas, is underlain without apparent physical evidence of hiatus by 350 to 500 feet of sandstones and sandy shales. These are definitely identified as the Fox Hills sandstone by their stratigraphic position above the Pierre shale, by their lithology, and by their marine invertebrates, which include the diagnostic index ammonite *Sphenodiscus lenticularis* Owen (Dobbin and Reeside, 1929, p. 18-20; Waage, 1939, p. 51). The upper limit of the Lance formation, following its original definition, is drawn at the top of the dinosaur-bearing beds. This upper limit coincides with a marked change, without a recognized erosional or structural unconformity, from the characteristic somber-colored shales and shaly sandstones of the typical Lance to a sequence of more persistent ridge-forming yellow sandstones, yellowish sandy shales, and workable coal beds. This overlying sequence of beds has been referred to the "Fort Union" formation on the basis of stratigraphic position, lithology, absence of dinosaurs, and presence of a typical lower Eocene flora, *i.e.*, Paleocene of the present report (Stanton and Knowlton, 1897, p. 134). In the author's opinion, the exact position of these beds within the so-called "Fort Union" is not yet adequately determined. Evidence will be presented to show that these beds are basal "Fort Union" and correspond to the nondinosaur-bearing Tullock and Ludlow beds and equivalents, which directly overlie the *Triceratops*-bearing beds of the Lance formation in Montana and the western Dakotas. In the present connection the significant facts regarding these beds are that they are stratigraphically above the typical Lance, are lithologically and florally distinct from the typical Lance, and are nondinosaur-bearing.

FLORA OF THE TYPE LANCE FORMATION

GENERAL CHARACTER

The flora of the Lance formation at its type locality comprises a total of 74 forms, of which eight are apparently new and six are determinable generically but not specifically. The presence of palms and other low latitude forms indicates that the flora is a lowland subtropical to warm-temperate assemblage of essentially the same facies as that of the Medicine Bow formation of southern Wyoming (Dorf, 1938, p. 25-30).

At present 60 of the 68 recognizable species of plants are known to occur elsewhere in late Cretaceous and early Tertiary formations. From the standpoint of correlation these species with outside distribution will be used as a basis for comparison and contrast with floras of known age.

RELATIONSHIP TO "FORT UNION" FLORA

As shown in Table 1 there are only five species (plus 2 ?) which are known to occur in the floras of both the type Lance and the "Fort Union" formations; one of these five species—*Ginkgo adiantoides*—is so wide ranging as to have little correlative significance. The contrast between the two floras is even more striking when it is pointed out that the "Fort Union" of Table 1 is used in its widest application to include the entire Paleocene, lying between the true Lance and the lower Eocene "Wasatch" (Wilmarth, 1938, p. 763). This Paleocene flora, moreover, is large and well known, so that the rarity of type Lance species in it cannot be reasonably ascribed to a lack of knowledge. The most recent available list of "Fort Union" species (Knowlton, 1919, p. 768) comprises about 175 identified species after excluding those restricted to Yellowstone Park, which are probably younger. About 110 identified species are known from the type Fort Union[1] and from other horizons whose Paleocene age is established by associated mammalian remains.[2] Revision of the Paleocene floras, recently undertaken by Dr. Roland W. Brown, of the United States Geological Survey, will probably combine many species in synonymy but will also probably reveal new species among the newly collected material. All these collections, as well as the type collections, at the United States National Museum were kindly made available to the author in the preparation of Table 1.

It is evident, then, that the floras of the typical Lance formation and the Paleocene "Fort Union" have less than 10 per cent of their species in

[1] In the vicinity of Buford, North Dakota (formerly Fort Union), near the mouth of the Yellowstone River (Newberry, 1898, p. 140-151; Ward, 1887, p. 13-115; Knowlton, 1913, p. 95).

[2] The type Melville formation (Simpson, 1937, p. 57; Douglass, 1902, p. 217; 1908, p. 11-13); the type Lebo member of the "Fort Union" (Stone and Calvert, 1910, p. 755); the so-called Tongue River member of the "Fort Union" of Billings County, North Dakota (Simpson, 1937, p. 11; Hares, 1928, p. 38, 39); and the type Paskapoo formation of the Red Deer valley, Alberta (Penhallow, 1908, p. 14; Berry, 1926, p. 189-209).

TABLE 1.—*Relationship of type Lance flora to the "Fort Union" flora*

Species	Type Lance	Fort Union
Asplenium tenellum	■	
Cornophyllum wardii	■	
Dryophyllum subfalcatum	■	
Ficus crossii	■	
F. trinervis	■	
Menispermites belli	■	
Myrica torreyi	■	
Nelumbo dawsoni	■	
Pistia corrugata	■	
Rhamnus salicifolius	■	
Viburnum montanum	■	
V. anomalinervum	■	
Vitis stantoni	■	
Canna? magnifolia	■	
Dombeyopsis obtusa	■	
Palaeoaster inquirenda	■	
Viburnum platanoides	■	
Sabalites montana	■	
Sequoia? longifolia	■	
Menispermites knightii	■	
Selaginella laciniata	■	
Quercus gardneri	■	
Ficus planicostata	■	
Aristolochia brittoni	■	
Carpites walcotti	■	
Carpolithus hirsutus	■	
Cissites lobatus	■	
Dammara? sp.	■	
Dombeyopsis trivialis	■	
Ficus post-trinervis	■	
Grewiopsis saportana	■	
Juglans leconteana	■	
Laurus wardiana	■	
Pistacia eriensis	■	
Rhamnus minutus	■	
R. marshallensis	■	
Salix lancensis	■	
Sassafras montana	■	
Magnoliophyllum cordatum	■	
Trochodendroides sp.	■	
Ficus ceratops	■	
Dombeyopsis colgatensis	■	
Phyllites colubrinoides	■	
Cissus lobato-crenata	■	
Sequoia dakotensis	■	?
Rhamnus cleburni	■	?
Ficus cockerelli	■	
Cinnamomum affine	■	
Zizyphus ripleyensis	■	
Viburnum marginatum	■	
Quercus viburnifolia	■	
Apeibopsis? discolor	■	
Laurus socialis	■	
Ficus uncata	■	
Fraxinus leei	■	
Trochodendroides nebrascensis	■	■
Ficus artocarpoides	■	■
Celastrus taurinensis	■	■
Trapa? microphylla	■	■
Ginkgo adiantoides	■	■

common. This is contradictory to the many published statements which stress the similarity between the Lance and "Fort Union" floras, as for example:

". . . the Lance-Fort Union flora . . . [is] . . . said by paleobotanists to be essentially one flora." (Dobbin and Reeside, 1929, p. 24).

". . . the abundant fossil plants . . . [of the Lance and equivalents] . . . appear to be distinctly Tertiary in aspect . . ." (Moore, 1933, p. 453).

"The flora of the Lance is dominantly of Fort Union aspect." (Shimer, 1934, p. 913).

Such statements probably owe their origin to the expressed views of Knowlton, whose latest opinion regarding the Lance flora (1930, p. 10) was as follows:

"The known Lance flora numbers about 125 forms, of which over 80 occur also in the overlying Fort Union formation."

It has been rather difficult to trace the origin of such a conclusion. The total of "about 125 forms" agrees with the total of 123 forms listed in Knowlton's (1919, p. 764) latest enumeration of Lance species. A comparison of these species with his listed "Fort Union" species (p. 768) shows that there are 65 rather than "over 80" species in common. This is still, however, about 52 per cent agreement between the two floras, in Knowlton's summary, in contrast to less than 10 per cent agreement shown in the present study.

Further investigation (Dorf, 1938, p. 33) has indicated that of Knowlton's 58 recorded localities of reputed "Lance" species, at least 10 localities, and probably as many as 14, are from horizons which have recently been shown to be in the "Fort Union" formation. Near Miles City, Montana, for example, Knowlton obtained plant collections from, among others, the following localities (1909, p. 188-190):

1. "Bluffs of Yellowstone opposite Miles City, 115-125 feet above river.
2. "Nine miles west of Miles City, Montana. Near NE. corner T. 7 N., R. 45 E.
3. "Klonders ranch, 18 miles east of Miles City; 100 feet below top of 'somber beds.'
4. "Signal Butte, 5 miles east of Miles City, 225 feet above base of section.
5. "Same locality as last but in upper member of 'somber beds.'"

All these localities are in the "somber beds" of Collier and Smith (1909, p. 39, 40), which they assigned to the "Fort Union" formation. Probably misled by the somber color, Knowlton (1909, p. 186) regarded these beds as Lance and equivalent to the dinosaur-bearing "Hell Creek beds." Subsequent work in the region (Thom and Dobbin, 1924, p. 494; Thom, Hall, Wegemann, and Moulton, 1935, p. 63; Pierce, 1936, p. 61; pl. 9) has shown that these localities are several hundred feet above the top of the true dinosaur-bearing Lance and are referable to the lower "Fort Union" (Lebo member [?]). Knowlton enumerated 29 species

from these localities; their inclusion in his so-called "Lance" flora obviously helped to give it a decided "Fort Union" aspect. A comparison of Knowlton's 29 species with their occurrences elsewhere clearly substantiates the reference of these beds to the "Fort Union"; in the following list of the 22 species with outside distribution, 19 are recorded from the type area of the Fort Union or from other horizons whose Paleocene age is established by associated mammalian remains, whereas only 4 of the 22 species are known definitely from the type Lance or its *Triceratops*-bearing equivalents:

†* *Celastrus taurinensis* Ward
(*C. wardii* of Knowlton)
Cornus newberryi Hollick
* *Corylus americana* Walter
* *C. rostrata* Aiton
* *Glyptostrobus dakotensis* Brown
(*G. europaeus* of Knowlton)
* *Hicoria antiquora* (Newberry) Knowlton
* *Onoclea sensibilis fossilis* Newberry
* *Paranymphaea crassifolia* (Newberry) Berry
(*Cocculus haydenianus* of Knowlton)
Platanus raynoldsii Newberry
* *Populus daphnogenoides* Ward
* *P. genetrix* Newberry
* *P. newberryi* Cockerell
* *Sapindus affinis* Newberry
* *S. grandifoliolus* Ward
†* *Sequoia nordenskiöldi* Heer
* *Taxodium occidentale* Newberry
†* *Trapa? microphylla* Lesquereux
* *Trochodendroides arctica* (Heer) Berry
(*Populus arctica* of Knowlton)
†?* *T. cuneata* (Newberry) Berry
(*Populus cuneata, P. cyclomorpha,* and *P. nervosa elongata* of Knowlton)
†* *T. nebrascensis* (Newberry) Dorf
(*Populus nebrascensis* of Knowlton)
* *T. speciosa* (Ward) Berry
(*Populus speciosa* of Knowlton)
* *Viburnum antiquum* (Newberry) Hollick

Apparently Knowlton also was misled regarding the stratigraphy in north-central Wyoming (1909, p. 212-214), for he included in his "Lance" flora 29 species obtained from horizons in this region which since then have been shown to be "Fort Union." These are from the following localities:

1. "Near Ilo [post office], Bighorn County, Wyoming; above 500 feet above base of beds.

2. "Two miles north of Ilo [post office], Bighorn County.

3. "Three miles northwest of Meeteetse, Wyoming. Black Diamond Mine. About 50 feet above base of section."

Subsequently the floral lists from these three localities were republished (Hewett, 1926, p. 35), being included by Knowlton with other lists from the "Fort Union" formation, which in this region is in places separated from the underlying *Triceratops*-bearing Lance by an angular unconformity. Knowlton's reference at this time of these localities to "Fort Union" horizons is amply corroborated; in the following list of the 21 species with outside distribution, 17 are known from the type Fort

* Known elsewhere in type Fort Union or other undoubted Paleocene horizons.
† Known elsewhere in type Lance or equivalent Upper Cretaceous horizons.

Union or other undoubted Paleocene horizons, whereas only 3 (+1?) are known from the true Lance or equivalents:

* *Berchemia multinervis* (Al. Braun) Heer
* *Celastrus ferrugineus* Ward
* *C. pterospermoides* Ward
†* *C. taurinensis* Ward
* *Corylus americana* Walter
† *Ginkgo adiantoides* (Unger) Heer
Magnolia tenuinervis? Lesquereux
* *Onoclea sensibilis fossilis* Newberry
Paliurus pulcherrimus Ward
* *Platanus haydenii* Newberry
* *P. nobilis* Newberry
P. raynoldsii Newberry
* *Populus daphnogenoides* Ward
* *Sapindus affinis* Newberry
* *S. grandifoliolus* Ward
* *Sequoia langsdorfii* (Brongniart) Heer
†* *S. nordenskiöldi* Heer
* *Trochodendroides arctica* (Heer) Berry
(*Populus arctica* of Knowlton)
†?* *T. cuneata* (Newberry) Berry
(*Populus cuneata* of Knowlton)
* *Viburnum antiquum* (Newberry) Hollick
* *V. asperum* Newberry
(*V. newberryanum* of Knowlton)

It is evident, then, that in several regions recent studies by a number of workers have helped to clarify the stratigraphic problems and uncertainties which were responsible for Knowlton's inclusion of a large number of typical Paleocene "Fort Union" species in his "Lance" flora. Lacking the subsequent refinements in stratigraphy, Knowlton was inevitably led to the conclusion that the Lance flora was made up in large part of true "Fort Union" species.

In order to point out the contrast between the flora of the type Lance formation and the known floras of more widespread Tertiary formations, Figure 2 shows clearly that only eight (about 13 per cent) of the Lance species with outside distribution occur elsewhere in the Tertiary. An additional eight species are reported only questionably from Paleocene or Eocene horizons and can therefore not be considered established. It is clear, then, that the flora of the type Lance formation contains only a minority, and probably a small minority, of species which are known also from Tertiary deposits.

RELATIONSHIP TO UPPER CRETACEOUS FLORAS

Turning from negative to positive relationships, Figure 2 shows that the type Lance flora is closely similar to the combined Hell Creek, Laramie,[3] and Medicine Bow floras, of generally accepted Upper Cretaceous age (Wilmarth, 1938, p. 938, 1150, 1334). From these floras are known no less than 54 (90 per cent) of the 60 Lance species with outside distribution; 28 species (about 47 per cent) are restricted to floras of this age. It is significant that usually these restricted index species are represented by a large number of specimens in the Lance and equivalent

* Known elsewhere in type Fort Union or other undoubted Paleocene horizons.
† Known elsewhere in type Lance or equivalent Upper Cretaceous horizons.
[3] In the Laramie flora are included the species known to occur in the lower Dawson and the Arapahoe-lower Denver formations (Dorf, 1938, p. 34 and Figure 8).

FIGURE 2.—*Relationship of type Lance flora to Upper Cretaceous and Tertiary floras*

formations, whereas the few Paleocene species are only sparsely represented.

The essential contemporaneity of the type Lance, Hell Creek, Laramie, and Medicine Bow formations is indicated not only by their floral similarity but also by their stratigraphic positions and their vertebrate and invertebrate faunas. They overlie conformably the widespread Fox Hills sandstone, which in each of the regions concerned carries diagnostic marine invertebrates including the zone-index ammonite *Sphenodiscus lenticularis* Owen (Stanton, 1910, p. 177; Dobbin and Reeside, 1929, p. 20, 21, 23; Dorf, 1938, p. 4, 7, 31; Waage, 1939, p. 56); they have in each region yielded characteristic uppermost Cretaceous dinosaurs of the *Triceratops* zone (Brown, B., 1914, p. 355-380; Dobbin and Reeside, 1929, p. 10, 11, 24; Stanton, 1909, p. 241, 246, 252); and they have yielded fresh-water invertebrates of essentially similar aspect (Henderson, 1935, p. 32-34; Stanton, 1909, p. 243, 247, 277, 285).

The Upper Cretaceous age of the type Lance flora is further assured by the downward extension of 22 species into the Montana group, as represented by the floras of the Fox Hills, Vermejo,[4] upper Mesaverde, and Judith River formations, as shown in Figure 2.

Considering all the evidence presented, both paleontologic and stratigraphic, it seems clearly established that the type Lance formation is of post-Montanan Upper Cretaceous age. Its fauna and flora are essentially similar to those of the *Triceratops*-bearing formations elsewhere, including the Hell Creek of Montana, the Medicine Bow of southern Wyoming, and the Laramie of Colorado.

FIGURE 2.—*Relationship of type Lance flora to Upper Cretaceous and Tertiary floras*

RELATIONSHIP TO THE TULLOCK-LUDLOW FLORA

Because of its peculiar significance in the Lance-"Fort Union" boundary discussion, the Tullock-Ludlow flora is considered here as a separate problem. As shown in Table 2, the Tullock and Ludlow beds were defined originally as the upper member of the Lance formation in south-central Montana and northwestern South Dakota, respectively. Evidence here presented indicates that these beds and their equivalents are younger than the true Lance formation and not a part of it and are both stratigraphically and paleontologically related more closely to the beds of the overlying "Fort Union."

The fact that the Tullock and Ludlow beds have been generally recognized as mappable units indicates their lithologic distinction from the

[4] The writer believes that the middle and upper portions of the Vermejo formation are more probably post-Montanan and of the same age as the type Lance, Hell Creek, Medicine Bow, and Laramie formations (Dorf, 1938, p. 35; Fig. 8).

underlying "somber beds" of the true Lance formation. It has been pointed out, moreover, that the Tullock and Ludlow are more easily separable from the underlying Lance than from the overlying "Fort Union" (Winchester, Hares, Lloyd, and Parks, 1916, p. 20; Rogers and

TABLE 2.—*Upper Cretaceous-lower Tertiary sequence as generally accepted up to 1936* Northeastern Wyoming, eastern Montana, and western North and South Dakota (Modified after Wilmarth, U. S. Geological Survey, 1925, 1932)

Age	Formations	Members
Tertiary Eocene [Paleocene]	Fort union	Tongue River
		Lebo shale
Tertiary ? Eocene? [Upper Cretaceous]	Lance	Tullock — Ludlow —Cannonball marine
		Hell Creek
Upper	Fox Hills sandstone	Colgate sandstone
Cretaceous		Sandstone (marine)
(Montana Group)	Pierre shale	(Marine)

Lee, 1923, p. 11, 29). Close genetic relationship to the "Fort Union" is indicated also by the apparent interfingering of the upper part of the Ludlow with the Lebo member of the "Fort Union" (Thom and Dobbin, 1924, p. 492; Fig. 2).

Table 3 shows that there is the same degree of contrast between the type Lance and the type Tullock-Ludlow floras as between the type Lance and the "Fort Union" (Table 1). Of the 60 species of the Lance flora with outside distribution only four (less than 7 per cent) are known to occur in the type Tullock or Ludlow. It is possible that this number may be increased with further collecting from the Tullock and Ludlow, as their known flora of 32 species is considerably smaller than the "Fort Union" flora. The relationship of these 32 species to those of the type Lance flora is, however, rather remote.

Further study of the Tullock-Ludlow flora shows its close similarity to the Paleocene "Fort Union" flora. From the type areas, the Tullock flora contains 11 species (Rogers and Lee, 1923, p. 34), the Ludlow, 28 species (Leonard, 1911, p. 526; Winchester, Hares, Lloyd, and Parks, 1916, p. 24; Hares, 1928, p. 29). After combining 7 species which are in common, the flora of the type Tullock-Ludlow comprises 32 species. As shown in Table 4, of the 21 species known elsewhere, 17 are from the typical Fort Union or other horizons whose mammalian remains indi-

TABLE 3.—*Relationship of type Lance flora to type Tullock-Ludlow flora*

Species	Type Lance	Type Tullock-Ludlow
Asplenium tenellum	■	
Cornophyllum wardii	■	
Dryophyllum subfalcatum	■	
Ficus crossii	■	
F. trinervis	■	
Menispermites belli	■	
Myrica torreyi	■	
Nelumbo dawsoni	■	
Pistia corrugata	■	
Rhamnus salicifolius	■	
Viburnum montanum	■	
V. anomalinervum	■	
Vitis stantoni	■	
Canna? magnifolia	■	
Dombeyopsis obtusa	■	
Palaeoaster inquirenda	■	
Viburnum platanoides	■	
Sabalites montana	■	?
Sequoia? longifolia	■	?
Menispermites knightii	■	
Selaginella laciniata	■	
Quercus gardneri	■	
Ficus planicostata	■	
Aristolochia brittoni	■	
Carpites walcotti	■	
Carpolithus hirsutus	■	
Cissites lobatus	■	
Dammara? sp.	■	
Dombeyopsis trivialis	■	
Ficus post-trinervis	■	
Grewiopsis saportana	■	
Juglans leconteana	■	
Laurus wardiana	■	
Pistacia eriensis	■	
Rhamnus minutus	■	
R. marshallensis	■	
Salix lancensis	■	
Sassafras montana	■	
Magnoliophyllum cordatum	■	
Trochodendroides sp.	■	
Ficus ceratops	■	
Dombeyopsis colgatensis	■	
Phyllites colubrinoides	■	
Cissus lobato-crenata	■	
Sequoia dakotensis	■	
Rhamnus cleburni	■	?
Ficus cockerelli	■	
Cinnamomum affine	■	
Zizyphus ripleyensis	■	
Viburnum marginatum	■	
Quercus viburnifolia	■	■
Apeibopsis? discolor	■	
Laurus socialis	■	
Ficus uncata	■	
Fraxinus leei	■	
Trochodendroides nebrascensis	■	?
Ficus artocarpoides	■	?
Celastrus taurinensis	■	■
Trapa? microphylla	■	■
Ginkgo adiantoides	■	■

cate Paleocene age, whereas only four are known from the true Lance or *Triceratops*-bearing equivalents.

The paleobotanical evidence for considering the type Tullock and Ludlow beds younger than the Lance and not the upper part of it is not con-

TABLE 4.—*Relationship of type Tullock-Ludlow flora to type Lance and "Fort Union" floras*

Species	Type Lance	Type Tullock-Ludlow	"Fort Union"
Celastrus pterospermoides		■	■
C. taurinensis	■	■	■
Ginkgo adiantoides	■	■	
Hicoria antiquora		■	■
Juglans rugosa		■	
Leguminosites arachioides		■	■
Onoclea sensibilis fossilis		■	■
Paranymphaea crassifolia		■	■
Platanus haydenii		■	■
P. nobilis		■	■
P. raynoldsii		■	
Populus daphnogenoides		■	■
Pterospermites whitei?		■	■
Sapindus affinis		■	■
S. grandifoliolus		■	■
Sequoia nordenskiöldi	■	■	■
Taxodium occidentale		■	■
Thuja interrupta		■	■
Trapa? microphylla	■	■	■
Trochodendroides cuneata		■	■
Viburnum whymperi		■	

tradicted by the known vertebrate evidence. Vertebrate paleontologists have insisted rightly on the restriction of the term "Lance" to the Upper Cretaceous *Triceratops*-bearing beds, as originally defined, and have placed the immediately overlying nondinosaur-bearing beds, including the Tullock, in the Paleocene "Fort Union" (Brown, B., 1914, p. 356; Simpson, 1929, p. 6; Jepsen, 1930, p. 463, 475; Russell, 1930, p. 145). Recently Simpson (1937, p. 20) has expressed the following opinion:

> "It is certain in some areas (notably Polecat Bench in northern Wyoming, as shown by Jepsen) and probable in most or all that strata generally referred to the Lance, often under the name of Tullock but not necessarily equivalent to the type Tullock, are in reality distinctly later than the typical Lance or the equivalent Hell Creek and both faunally and stratigraphically are more nearly related to the overlying beds, that is, to the Fort Union."

Such a view is now substantiated by positive floral evidence not only of the floras of the nondinosaur-bearing Tullock and Ludlow at their type localities, as already presented, but also of the floras of the nondinosaur-bearing beds at other localities. Moreover, it becomes obvious that

Knowlton's inclusion in his "Lance" flora of species from these latter localities resulted in a further mixture of Paleocene and Upper Cretaceous species. It is quite clear, for example, that the following of Knowlton's "Lance" localities are in reality from the nondinosaur-bearing beds above the true Lance:

1 (a). "Six miles east of Miles City and 15 feet above the Kircher coal:" 4 species; (b) "Miles City field, SW. ¼ sec. 22, T. 8 N., R. 47 E., about 50 feet below the Big Dirty coal bed:" 11 species (Knowlton, 1909, p. 188, 189).

Both these localities are above the true dinosaur-bearing Lance in beds which have been traced, both lithologically and by persistent coal beds, westward into the type Tullock (Dobbin, 1929, Pl. 8; Pierce, 1936, p. 60). Of the 11 species with outside distribution, 10 are known from undoubted Paleocene, whereas only one is known to occur also in the true Lance or equivalents. A list of all the species from these and the following six localities is presented on page 228.

2. "Widdecomb Bros. ranch, northeast of Melville, Montana; sec. 29, T. 6 N., R. 16 E.:" 12 species (Knowlton, 1909, p. 194).

Recent work in this area places this locality definitely in beds lying 500 feet or more above the true dinosaur-bearing Lance (Simpson, 1937, p. 15, 57, Pl. 1). The horizon is either in the uppermost Bear formation (= Tullock?) or the lowermost Lebo. Of eight species with outside distribution, seven are known elsewhere from unquestionable Paleocene, and none has ever been reported from the type Lance or its *Triceratops*-bearing equivalents.

3. "Mouth of Cedar Creek, 11¾ miles above Glendive, Montana, 400 feet above Pierre:" 8 species (Knowlton, 1909, p. 197).

This locality is about 200 feet above the *Triceratops*-bearing Hell Creek beds, in strata which are probably equivalent to the Tullock farther west (Brown, R. W., personal communication, December, 1938). All the seven species with outside distribution are known elsewhere in undoubted Paleocene beds, and none is reported from the type Lance or equivalents.

4. Near Yule, North Dakota, 250 to 300 feet above the somber beds containing dinosaurs; 9 species (Knowlton, 1909, p. 202).

As specifically stated, this locality is well above the dinosaur-bearing Lance in beds which have since been mapped as Ludlow (Hares, 1928, p. 24; Stanton, 1920, Fig. 1). Of the nine species with outside distribution, seven are known elsewhere in undoubted Paleocene beds, whereas only one is reported from the type Lance or equivalents.

5. "McCord coal bank, in NW. ¼ sec. 5, T. 129 N., R. 88 W.," North Dakota: 9 species (Knowlton, 1909, p. 202).

This locality is in beds lying just below the base of the marine Cannonball member of the Ludlow and undoubtedly should be included in the Ludlow, as the dinosaurs in the "lower Lance" of this region are known only from horizons several hundred feet below the Cannonball (Winchester, Hares, Lloyd, and Parks, 1916, p. 23, 24). The eight species with outside distribution are all known from the Paleocene; only two are known also from the type Lance or equivalents.

6. "Seven Mile Creek, 40 miles northwest of Edgemont," South Dakota, "from the base of the series of lignites overlying the Converse County beds": 7 species (Brown, B., 1907, p. 842; Knowlton, 1909, p. 203).

As stated by Knowlton, these beds overlie the *Triceratops*-bearing "Converse County" beds (= true Lance); they have since been referred to the Ludlow by Thom and Dobbin (1924, p. 492). Only three species are identified specifically, of which two are known from the Paleocene and one from the type Lance or equivalents.

7. (a) "About 1½ miles northeast of Dayton, Wyoming": 5 species; (b) "2¼ miles northeast of Ranchester, Wyoming": 9 species; (c) "2½ miles southeast of Ranchester, Wyoming": 3 species; (d) "Slater Creek, 6 miles northeast [actually northwest] of Monarch, Wyoming": 7 species (Knowlton, 1909, p. 211).

All these localities are in beds referred to the De Smet formation (Darton, 1906, p. 8, and areal geology map) and are in horizons several hundred feet above the dinosaur-bearing Piney shale (= Lance), as pointed out by Stanton (1909, p. 266). Of 14 species with outside distribution, 12 are known from undoubted Paleocene beds, whereas none has been reported from the type Lance or its equivalents.

Summarizing the evidence from these localities, there are 38 identified species with outside distribution, as shown in the following list, in which the numbers in parentheses refer to the localities already mentioned:

* *Ampelopsis xantholithensis* (Ward) Cockerell (*Vitis xantholithensis* of Knowlton)—(2).
* *Aralia notata* Lesquereux—(2).
* *Celastrus montanensis* Knowlton and Cockerell—(1b).
* *C. pterospermoides* Ward—(1b).
†* *C. taurinensis* Ward (*C. curvinervis* of Knowlton)—(1b, 5).
* *Corylus rostrata* Aiton—(3).
Credneria daturaefolia Ward—(2).
Diospyros haguei Knowlton—(1b).
* *Elaeodendron polymorphum* Ward—(1b, 3).
* *Glyptostrobus dakotensis* Brown (*G. europaeus* of Knowlton)— 1a, 3, 7a).
* *Grewiopsis platanifolia* Ward (1b).
* *G. populifolia* Ward—(1b).
* *Hicoria antiquora* (Newberry) Knowlton—(4, 7c).
Juglans rugosa Lesquereux—(4).
* *Leguminosites arachioides* (Lesquereux) Lesquereux (2, 7d).
* *Paliurus pealei* Ward?—(5).
* *Paranymphaea crassifolia* (Newberry) Berry (*Cocculus haydenianus* and *Aristolochia crassifolia* of Knowlton)—(3, 4, 5).
* *Platanus guillelmae* Göppert—(7a).
* *P. haydenii* Newberry—(4).
* *P. nobilis* Newberry—(7b, 7d).
P. raynoldsii Newberry—(6).
* *Populus daphnogenoides* Ward—(2, 5).
* *P. genetrix* Newberry—(2, 3, 7d).

* Known elsewhere in type Fort Union or other undoubted Paleocene horizons.
† Known elsewhere in type Lance or equivalent Upper Cretaceous horizons.

* *P. newberryi* Cockerell (*P. acerifolia* of Knowlton)—(1b, 5).
* *Pterospermoides cupanoides* (Newberry) Knowlton (*Phyllites cupanoides* of Knowlton)—(2).
* *P. minor* Ward—(3).
* *P. whitei* Ward—(3).
* *Sapindus affinis* Newberry—(4, 7b).
* *S. grandifoliolus* Ward (1b, 5, 7c).
†* *Sequoia nordenskiöldi* Heer—(5, 6).
Sparganium stygium Heer—(7b).
* *Taxodium occidentale* Newberry—(4, 6, 7b).
* *Thuja interrupta* Newberry—(5).
†* *Trapa? microphylla* Lesquereux—(4).
* *Trochodendroides arctica* (Heer) Berry (*Populus arctica* of Knowlton)—(7a).
†?* *T. cuneata* (Newberry) Berry (*Populus amblyrhyncha* and *P. cuneata* of Knowlton)—(1a, 1b, 2, 4, 5, 7d).
* *Viburnum antiquum* (Newberry) Hollick—(1b).
V. whymperi Heer—(4, 7d).

This list shows that 31 of the 38 species are known elsewhere in "Fort Union" beds whose Paleocene age is known from associated mammalian remains, whereas only three (plus 1 ?) are known from the type Lance or equivalent *Triceratops*-bearing beds. All three of the species known from the Lance or equivalents occur also in the true "Fort Union." It is clear, therefore, that the paleobotanical evidence substantiates the evidence of lithology, stratigraphic position, and absence of dinosaurs for considering these beds distinctly younger than the true Lance, and Paleocene rather than Upper Cretaceous. When it is realized that all the species in this list were included by Knowlton in his "Lance" flora, it becomes even more obvious that the stratigraphic units considered Lance included more than the true *Triceratops*-bearing beds. Much of the paleobotanical confusion regarding the Lance and Fort Union floras could have been averted if the flora of the beds which had actually yielded dinosaurs had been properly segregated from the immediately overlying beds which had not yielded dinosaurs, as was suggested at an early date by Stanton (1909, p. 286, 287).

The view that the floras of the type Tullock and type Ludlow, as well as their nondinosaur-bearing equivalents elsewhere, are distinct from the true Lance and other beds of the *Triceratops* zone and are of Paleocene aspect has already been discussed (Dorf, 1937; 1938, p. 33, 35; Fig. 8). This opinion was subsequently substantiated by Brown (1938, p. 421) on the basis of his studies of the "Fort Union" floras and collections from the Hell Creek beds of Montana and the Dakotas. The previous consensus of opinion regarding the age and relationships of the Lance-Fort Union sequence is shown in Columns I to III of Table 5, compiled from Wilmarth's recent Lexicon. Column I is based on the following statement (Wilmarth, 1938, p. 1142):

"(1) The Hell Creek and Tullock deposits (previously classified as members of Lance formation) were raised to formation rank; (2) the age of Hell Creek formation was changed to *Upper Cretaceous* from *Tertiary? Eocene?;* (3) the age of Tullock formation was changed from Tertiary (?) to *Upper Cretaceous* or *Eocene.*"

* Known elsewhere in type Fort Union or other undoubted Paleocene horizons.
† Known elsewhere in type Lance or equivalent Upper Cretaceous horizons.

TABLE 5.—*Recent changes in interpretation of Lance-"Fort Union" relationships and present opinion*

Compiled from Wilmarth (1938). Abbreviations have been written in full.

I		II			III		IV		
Mainly Southern Montana		Mainly Western Dakotas			Mainly Northeastern Wyoming		Proposed revision		
Eocene (early)	Fort Union formation	Eocene (early)	Fort Union formation		Eocene (early)	Fort Union formation	Paleocene	Fort Union group	Several Formations (Not discussed in this report)
Eocene or Upper Cretaceous	Tullock formation	Upper Cretaceous	Lance formation	Ludlow member	Eocene and Upper Cretaceous or Upper Cretaceous	Lance formation			Tullock formation (=Ludlow formation and Cannonball marine member)
Upper Cretaceous	Hell Creek formation			Cannonball marine member			Upper Cretaceous		Lance formation (=Hell Creek formation)
	Fox Hills sandstone		Fox Hills sandstone		Upper Cretaceous	Fox Hills sandstone			Fox Hills sandstone
	Pierre shale		Pierre shale			Pierre shale			Pierre shale

The evidence here presented would propose the modification that the Tullock formation be classified as Paleocene, as shown in Column IV of Table 5.

Column II is based on the following statement (Wilmarth, 1938, p. 1234):

"The U. S. Geological Survey now classifies Cannonball marine member of Lance formation and the demonstrably equivalent part of the Ludlow member as Upper Cretaceous."

The evidence presented indicates that the Ludlow is stratigraphically and florally younger than the true *Triceratops*-bearing Lance formation of the Upper Cretaceous and is genetically and florally not separable from the Paleocene "Fort Union." The fauna of the Cannonball marine member, which interfingers with the Ludlow, has been referred to the Upper Cretaceous by Stanton (1920, p. 13), who states:

"The Cannonball fauna has the general aspect of a Tertiary fauna on account of the absence of most of the exclusively Mesozoic types and the preponderance of long-lived modern types, but its close relationship with the Cretaceous is shown by the fact that 24 of its species (40% of its known molluscan fauna) are identified with species found in the late Cretaceous formations of the same general region, and 18 of the species (30%) are known in the Fox Hills fauna."

This fauna is a difficult one to evaluate, due to the absence of younger marine faunas in this same area with which comparison might be made. It seems significant, however, that such typically Fox Hills Cretaceous genera as *Sphenodiscus, Baculites, Scaphites, Belemnitella, Inoceramus, Nemodon,* and *Linearia* are wholly missing in the Cannonball beds, whereas they have yielded a number of species closely similar to or identical with Midway and Wilcox species of the Gulf Coast Eocene as well as two genera—*Calyptrophorus* and *Cylichnella*—which are not known definitely to occur in pre-Tertiary faunas (Stanton, 1920, p. 13). That a Paleocene age reference for the Cannonball is not considered unlikely or unsupported by evidence is shown by the recent statement of Stephenson and Reeside (1938, p. 1636):

"A still higher marine zone of small extent (Cannonball) has been considered Cretaceous but may well be basal Eocene (Paleocene of European section)."

In Column III of Table 5 is shown the status of the Lance-Fort Union sequence of other areas, based on the following statement (Wilmarth, 1938, p. 1142):

"(4) in areas in Montana and northeastern Wyoming where the Hell Creek and Tullock are not recognizable, the age of the Lance was changed to *Upper Cretaceous,* except where Eocene fossils are found above Cretaceous fossils, in which case the age of the Lance is to be *Cretaceous and Eocene;* (5) the age of the Lance in other parts of Wyoming (outside northeastern part of State) is to be *Upper Cretaceous,* no Eocene flora having been reported from these areas;"

It is here proposed that "where Eocene fossils are found above Cretaceous fossils" within the so-called Lance, the Eocene [Paleocene] fossils are undoubtedly from beds equivalent in age to the Tullock or Ludlow and are referable to the Paleocene "Fort Union" but not a part of the true Lance. There is no confusion "in other parts of Wyoming" because in these areas the Tullock-Ludlow equivalents have been separated from the beginning of study both paleontologically and lithologically from the true Lance and properly placed in the "Fort Union." In the Lance Creek area, for example, the basal "Fort Union" is traceable directly northward into the beds which Dobbin and Barnett (1927, p. 9) have included in the Tullock of the Gillette coal field. These beds are definitely above the traceable upper limit of the true Lance, as originally defined, and are lithologically distinct from the underlying dinosaur-bearing beds, which Dobbin and Barnett (1927, p. 8) have referred to the Hell Creek beds. Fossil plants obtained from these beds above the type Lance in the Lance Creek area and from their northward extension leave no doubt as to their correct original assignment to the "Fort Union." In the following list of the 18 species known to occur elsewhere, 13 are found in undoubted Paleocene beds whereas only two are known anywhere from the true Lance or its equivalents:

Knowlton collection (1897, p. 134, 136)
**Ampelopsis montanensis* Cockerell
(*Vitis cuspidata* of Knowlton)
**Celastrus pterospermoides* Ward
†**C. taurinensis* Ward
**Cornus newberryi* Hollick
**Diospyros brachysepala* Al. Braun
Grewia celastroides Ward
**G. crenata* (Unger) Heer
Parrottia cuneata (Newberry) Berry
(*Viburnum cuneatum* of Knowlton)
Platanus raynoldsii Newberry
†**Sequoia nordenskiöldi* Heer
**Zizyphus serrulatus* Ward

Princeton collection
Anemia lanceolata Knowlton
†**Celastrus taurinensis* Ward
**Glyptostrobus dakotensis* Brown
**Hicoria antiquora* (Newberry) Knowlton
**Onoclea sensibilis fossilis* Newberry
Platanus coloradensis Knowlton
**Sapindus affinis* Newberry
†**Sequoia nordenskiöldi* Heer
**Thuja interrupta* Newberry

CONCLUSIONS

1. The flora of the Lance formation at its type locality is definitely not a "Fort Union" flora. Less than 10 per cent of the type Lance species occur also in the type Fort Union formation or other beds of definite Paleocene age. Previously published statements pointing out the similarity between the Lance and "Fort Union" floras were based on misconceptions in stratigraphy, resulting in the inclusion in the "Lance" flora of species obtained from beds now shown to be in part referable to the "Fort Union."

* Known elsewhere in type Fort Union or other undoubted Paleocene horizons.
† Known elsewhere in type Lance or equivalent Upper Cretaceous horizons.

2. The flora of the type Lance formation is clearly of Upper Cretaceous and not Paleocene character. Exactly 90 per cent of the type Lance species are known elsewhere only from the Upper Cretaceous, and 47 per cent are known exclusively from the beds of the *Triceratops* zone, which includes the Hell Creek formation of Montana and the Dakotas, the Medicine Bow of southern Wyoming, and the Laramie-lower Denver of Colorado. These formations, as well as the type Lance formation, occupy the same stratigraphic position conformably above the Fox Hills sandstone and constitute the latest true Upper Cretaceous sediments of the Rocky Mountain region.

3. The flora of the type Lance formation is clearly distinct from the known floras of the nondinosaur-bearing beds (including the Bear and Tullock formations and the Ludlow member of the "Lance"), which immediately overlie the true *Triceratops*-bearing Lance or Hell Creek formations. The flora of these nondinosaur-bearing beds is closely related to the Paleocene "Fort Union." Fossil plants from these beds were included previously in the so-called "Lance" flora, thus further accentuating its supposed "Fort Union" aspect.

4. The paleobotanical evidence supports the known vertebrate evidence in placing the boundary between the true Lance and the "Fort Union" at the base of the nondinosaur-bearing Tullock, Ludlow, or Bear formations or their equivalents; or, in other words, at the top of the *Triceratops*-bearing Hell Creek or Lance formations, as originally defined. Such a view is not contradicted by the marine invertebrates of the Cannonball beds, which interfinger with the Ludlow and the lower "Fort Union."

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GRANITIZATION NEAR KILLARNEY, ONTARIO

BY TERENCE T. QUIRKE

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ABSTRACT

Near Killarney, Ontario, the Killarnean granitic intrusions are associated with recognizable Huronian formations and with a "stony porphyry"[1] of questionable origin. The writer previously has described this rock as an ultra-metamorphosed quartzite, but later writers have declared that it must be of intrusive magmatic origin.

Unmistakable transitions along the strike from this porphyry into parts of the Gowganda formation have been discovered on George Lake, about 6 miles from Killarney along the general strike of rocks of disputed origin.

The contact between Huronian rocks of familiar type and those in the Huronian-Killarnean complex strikes nearly straight from Killarney toward the southeastern corner of Wanapitei Lake. The contact zone is complicated by intense shearing of intrusions within the Huronian sedimentary formations older than the main displacement, followed by widespread granitization of Huronian rocks, by igneous intrusion of very coarse porphyritic granite in large dikes within the displacement zone, and by the injection of dikes into the Huronian rocks west of the line of major disturbance. All these intrusive and transitional rocks must be distinguished from one another in relation to the various recognizable Huronian formations.

The Killarney locality is important because it shows extensive granitization and very significant rock transitions within a relatively small area.

INTRODUCTION

Near Killarney there are four distinct types of rocks: (1) The Killarney granite, (2) a stony porphyry, (3) Huronian quartzites, conglomerates, marbles, and graywackes, and (4) a microcline-rich migmatite of Hängo type. The granite is severely sheared and shows a cataclastic texture in places where, consequently, it is a Killarney granite gneiss. The dense porphyry lies against the Killarney granite and granite gneiss; it is generally unsheared and shows pronounced parallel, bedding-like joints; the groundmass is stony or finely crystalline, and most of the phenocrysts (probably porphyroblasts) are less than 5 mm. in diameter. The sedimentary rocks all show effects of high temperature, high pressure, and high stress metamorphism. The migmatite is a uniform, dense, pink granulite free of shearing zones, streaks of dark minerals, or other banding. This paper attempts to describe the geological relationships between these rocks and to satisfy certain criticisms of earlier reports.

Furthermore, this locality appears to be useful in affording an example of the apparent identity under favorable conditions of the end products of ultra-metamorphism and of magmatic intrusion. As Fenner (1931, p. 553-554) has concluded:

> "Thus we have excellent authority for believing that pneumatolysis or a high grade of hydrothermal metamorphism frequently produces the same or very similar assemblages of minerals as orthomagmatic crystallization and this is a source of very real difficulty in petrogenic interpretations . . . . In not a few descriptions, alteration effects which have been pointed to as illustrating the reaction principle in magmas, seem equally explicable as results of hydrothermal metasomatism. Processes so fundamentally unlike may lead to almost identical results, and the implications and conclusions to be drawn are entirely at variance."

[1] The writer is retaining the terms "porphyry" and "phenocryst" with a purely textural meaning in this paper, in order that the reader may the more easily correlate the new work here reported with that previously published.

Any evidence which throws light upon the problems of petrogenesis is valuable. The reality of granitization of sedimentary rocks is widely accepted, but the extent and the mechanics of the process are still matters of debate. The general status of the problem has been summarized recently by MacGregor and Wilson (1939), after this paper had been submitted for publication.

George Lake affords another locality where granitization of sedimentary rocks may be seen in various stages of completion and in considerable areal extent.

FIELD WORK AND ACKNOWLEDGMENTS

During the seasons of 1930 and 1931 the writer continued his study of parts of the Killarney contact zone. This was the more timely because certain parts of previous work by Quirke and Collins (1930) had not been concurred in by later workers.

The writer desires to express his deep obligation to the Geological Survey of Canada which for many seasons generously maintained his field studies, and particularly to the former Director, the late W. H. Collins, and to acknowledge the help of other professional colleagues, especially those whose criticisms have helped to make the later studies more critical and significant. He takes pleasure in acknowledging the help of Professor F. F. Grout who accompanied him to Killarney for a few hours in 1930.

LOCUS AND NATURE OF CONTACT ZONE

Field studies of 1931 indicate that various areas uniformly mapped as Killarnean granite contain different types of rock. Near Wavy Lake, there is a definite line of contact with sheared porphyritic syenite on the east side, but the granite masses formerly mapped on the west side of this line of contact are really dikes and other small masses quite unlike the large masses of sheared porphyry at the contact (Fig. 1).

Apparently the main line of contact, from Killarney to George, and from Kakakise, Brushcamp, Bell, Annie, and Wavy lakes to Dill and Crerar has a nearly straight course. It is marked by evidence of brecciation and shearing of the sedimentary formations and by intrusion of a sheared porphyry at various places, notably between Annie and Wavy lakes. It separates relatively slightly disguised Huronian sedimentary formations on the west from profoundly metamorphosed sedimentary rocks on the east. Freeman (1934) has reported minor masses and dikes of granite, syenite, and tonalite, for the most part unsheared and undeformed since emplacement on the west side, but on the east side there are few if any transverse dikes of granite and no unsheared granitic,

syenitic, or tonalitic intrusions. On the other hand, on the east side of the line the rocks are generally well bedded, granulitic gneisses which are interrupted by highly sheared porphyritic masses with rather definite contacts parallel to the bedding of the country gneisses.

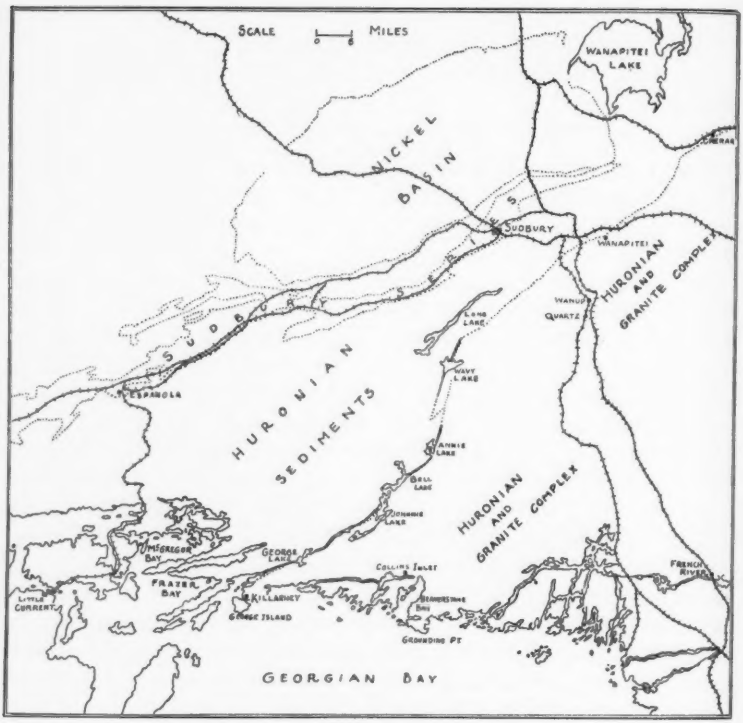

FIGURE 1.—*Map of the Killarney contact zone*
Showing position of Killarney area in relation to Sudbury district.

GEOLOGICAL CONTACTS AT KILLARNEY

DISSENTING OPINIONS OF OTHER WORKERS

The granite and its contacts at Killarney have been previously described in detail by Collins (1925, p. 85-93) and Quirke and Collins (1930, p. 31-102), and more recently by Jones (1930, p. 39-60). Jones has made field observations, careful petrographic studies, and numerous chemical analyses. His observations and collections are confined to the Killarney peninsula. In general his observations lead him to conclusions

different from those of Quirke and Collins. Lawson (1929, p. 361-383) disagrees with the work of the present writer at Killarney. Both Jones and Lawson conclude that the so-called fine porphyritic gneiss is younger than the coarse Killarney granite and thereby differ not only with Quirke and Collins (1930) but with all other geologists who have written about the area.

RESULTS OF PETROGRAPHIC STUDIES

In discussing first the petrographic studies of Jones, the writer notes differences of interpretation of the same petrographic features, which brings to mind the timely warning of Sederholm (1923, p. 15) against the use of petrographic methods when they lead to equivocal conclusions when compared with field evidences.

The petrographic arguments of Jones are based on the premise that the rocks are common plutonic igneous rocks which have crystallized in place from a liquid silicate melt. Quirke (1927, p. 766-770) has described and illustrated almost the same features as those illustrated and described by Jones with an entirely different conclusion due to his premise that the rocks are of metamorphic origin and have been formed in the solid from sediments by metasomatic replacement and recrystallization of old constituents during periods of stress.

The writer concedes the justice of Jones' arguments on the basis of his premise but he cannot accept the premise in the light of field evidence. Reynolds (1936, p. 404) has stated anew very clearly

> "The fact that a rock exhibits an 'igneous' appearance, both in hand-specimen and microscopic section, and is of igneous composition does not constitute evidence that it crystallized from a magma". With specific application to the points at issue, she adds (Reynolds, 1936. p. 405), ". . . such structural, textural, and chemical features of the rocks of the Killarney area, Ontario, have been presented by Jones (1) as if they were evidence unfavorable to Quirke's (2) conclusions that the rocks result from the transfusion of quartzite. Actually, however, not one of the facts cited by Jones is inconsistent with such a metasomatic origin".

Nevertheless, Jones has presented an alternative interpretation of what the present writer thought were petrographic supports to his own arguments; the writer dismisses them from further discussion at this time.

BEARING OF AVAILABLE CHEMICAL ANALYSES

Jones has made a number of chemical analyses both across the structure of these rocks and along their strike. His analyses are said to show that there is no perceptible gradation from the fine-grained stony porphyry to the Killarney granite but that the two rocks are almost identical chemically. He finds a distinct difference in composition between the quartzite and the stony porphyry with a narrow "gradation" between. In general, however, the chemical evidence seems to be inconclusive as to the main questions at issue in this paper.

SIGNIFICANCE OF FINE-GRAINED DIKES

Both Jones (1930, p. 48) and Lawson (1929, p. 363) record fine-grained porphyritic granite gneiss dikes cutting the coarse-grained granite gneiss. They interpret these dikes as members of the fine-grained porphyritic granite gneiss and conclude that this relation indicates that the fine-grained gneiss (stony porphyry) is younger than the coarse-grained gneiss (Killarney granite). As a matter of fact fine-grained dikes are common in all the gneissic rocks not only of the Killarney locality but throughout the region of Georgian Bay. Indeed on the southwestern shores of George Lake numerous dikelets of this type cut the fine-grained as well as the coarse-grained rocks. Consequently the presence of fine-grained dikes cutting the coarse-grained gneiss does not prove that the contiguous fine-grained gneiss is younger than the coarse-grained gneiss.

CONTACTS OF THE PORPHYRY ACCORDING TO JONES

The contact on the west side of the stony porphyry was interpreted as a very sharp gradation into the Killarney granite by Quirke and Collins (1930, p. 52-53). Jones (1930, p. 48, 56) later described it as an abrupt contact in several places; he described the eastern contact of the porphyry against quartzite as a narrow transition. The writer has also seen the abrupt contacts, as well as gradations, on the west side of the porphyry.

CONTACTS OF THE PORPHYRY ACCORDING TO LAWSON

Lawson's (1929, p. 363-364) description of the eastern contact is as follows:

> "In the porphyry to the east of Killarney are several large inclusions of quartzite. . . . In the vicinity of these large inclusions of quartzite there are many smaller ones and some inclusions of the granite gneiss. Dikes of the porphyry cut the quartzite and show chilled margins, which resemble the quartzite adjoining and which have been mistaken for quartzite. The porphyry is clearly later than the granite gneiss and is the rock which displays most of the intrusive phenomena which have been ascribed to the granite at Killarney. The porphyry extends along the north shore of Lake Huron from the village of Killarney to the granite gneiss at a point a short distance inside of Collins Inlet, at which the relations of the two rocks were not observed. The east-west extent of the porphyry is thus about 7 or 8 miles. To the east of the porphyry the granite gneiss is very extensive."

The writer has been unable to discover the porphyry dikes with chilled margins which Lawson says cut the quartzite. Jones evidently found nothing of the sort. Jones says the contact is a "transition", which is exactly the relation described by Quirke and Collins. Lawson's statement that the porphyry is "clearly" later than the granite gneiss needs some interpretation or amplification, because neither Knight (1915, p. 228), nor Quirke, nor Collins could have agreed to such a report.

Speaking of the contact between the Killarney granite and the felsitic porphyry· Knight (1915, p. 288) says:

> "In places the coarse-grained variety intrudes and holds fragments of the rhyolitic facies, but at other contacts the fine-grained type grades into the coarse-grained granite."

This is exactly opposite to the geological relations postulated by Lawson. Lawson states further that he did not observe the relations of the rocks at the eastern margin of the fine-grained rock in Collins Inlet, but that the granite gneiss is very extensive east of the contact. From Lawson's statement it appears that the porphyry is an intrusive mass within a single mass of granite gneiss. As a matter of fact the rocks on the east side of the porphyry are quartzite and well-bedded, heterogeneous gneisses unlike the nearly massive, coarse granite gneiss at Killarney, but having a structure quite in accord with that of both the "included" quartzite and the fine-grained porphyry. Furthermore Lawson ascribes "most of the intrusive phenomena" not to the coarse-grained Killarney granite but to what he describes as a fine-grained porphyry. His so-called "intrusion", although over a mile wide and at least 8 miles long, is approximately uniform in composition both across and along the strike according to Jones' chemical analyses and shows no signs of differentiation and practically no signs of contact metamorphism according to both Jones and Lawson. Clearly if it be an intrusion at all it is one which solidified with very little excess heat and a small quantity of excess mineralizers. It is not clear to the writer what Lawson refers to as "the intrusive phenomena" in this connection, and his later reference to "the ramification of apophyses of porphyry through the quartzite" requires explanation. The writer and his field associates, in 1930 and 1931, searched carefully but in vain for these apophyses of porphyry in the quartzite east of Killarney.

STRUCTURAL FEATURES OF THE PORPHYRY

Neither Lawson nor Jones reconcile, with their interpretation of the stony porphyry as an intrusion, the fact that it is markedly well bedded and that its structure continues that of the quartzitic, so-called "inclusions." In spite of that difficulty Jones (1930, p. 40, 51, 52) has clearly included the structure in his geological description, but Lawson does not mention it.

The marked sedimentary character of the bedding structure of the fine, porphyritic gneiss is well shown in a photograph published by Knight (1915, Fig. 7). This picture shows the bedded appearance of the stony porphyritic gneiss which is the outstanding structural characteristic of the rock. It does not look to the writer like an intrusive porphyry, especially in view of its dimensions—8 miles long and a mile wide.

In August 1930 Professor F. F. Grout called the writer's attention to certain apparently anomalous dark streaks in the fine gneiss near the quartzitic masses northeast of the east lighthouse. These streaks are V-shaped; in many cases the V's lie on their sides, in pairs point to point, directed along the bedding structure. Evidently these could not represent cross-bedding in a sediment nor do they resemble any structure found in volcanic or injected rocks. However, similar structures were later found in the quartzite masses near-by, wherein they appear to be the intersection of co-ordinated cross fractures, features common in quartzites. In this locality this has a special interest, because Collins (1930, p. 46) discovered streaks in the pink, fine-grained gneiss which looked to him like the residuals of quartz pebbles found in the Lorrain quartzite well shown in the same locality. This gradation shows on the bare rocks near the shore on the northwest side of the little quartzite islands about half a mile northeast of the east lighthouse. Massive fine-grained porphyritic gneiss contains little sericite streaks over 100 feet from the main quartzite mass. Closer to the quartzite mass the sericitic streaks are more abundant and still closer sericitic and cherty streaks appear, the cherty streaks become strips and masses of quartzite within pink gneiss, and finally the pink gneiss is absent and the rock is quartzite. All the streaks, strips, and masses of quartzite are parallel; none are twisted or apparently tilted out of position as might be expected if they had been stoped out of place by a subjacent or adjacent injection. Even the minor structures found in the quartzites are preserved in the fine-grained gneiss together with the bedding planes. Nevertheless, throughout the fine porphyritic gneiss the bedding structure becomes definitely pronounced and nearly lacking in different places along the general strike of the rock. Near the large quartzite remnants northeast of the east lighthouse some of the fine-grained gneiss is nearly massive in places. Grout agreed that the fine-grained porphyry gneiss looks like an igneous rock and he also recognized a sharp contact between the fine and coarse gneisses near Killarney channel, as noted by Jones and Lawson, and an interbanding in places of one rock with the other, as noted by Jones, Quirke, and Collins.

FINE-GRAINED CONTACT AND GRADATIONAL CONTACTS

The appearance of extremely fine grained texture at the contact between coarse and fine gneiss was recognized by the writer only after the publication of the papers by Lawson and Jones. It is extremely narrow where seen by the writer—at no place more than 1 inch wide and in most places not visible at all. Where this sort of narrow discolored selvedge was found by the writer it may be due to a number of different processes. It might be due to chilling of an intrusive mass as suggested by Jones

and Lawson, it might be due to leaching of dark minerals near the surface of contact by ground waters, it might be due to a sort of mylonization followed by fine recrystallization, and it might be a hornfelsic baking effect produced by the intrusion of the coarse granite gneiss after the development of the fine-grained gneiss. The work of Jones and Lawson drew attention most usefully to this definite line of contact, which is abrupt in places, but which is gradational elsewhere (Jones, 1930, p. 48), and which was described on the basis of the exposures seen by Quirke and Collins as a gradation.

RELATIONS BETWEEN GRANITE, PORPHYRY, AND SEDIMENTARY ROCKS NEAR GEORGE LAKE

GENERAL CONSIDERATIONS

In the opinion of the writer the most significant contacts near Killarney are those between the well-bedded, fine-grained porphyry and the quartzite near the east lighthouse. To him they appear to show unmistakably the identity of the quartzite and the porphyry. However, inasmuch as Lawson (1929) considered the contacts to be intrusive, perhaps other observers would appreciate more definite field evidences. Near the east lighthouse at Killarney the contacts are relatively abrupt, for the most part across the strike, and consequently simulate igneous contacts. Accordingly the writer returned to George Lake, near Killarney, in search of a gradation along the strike, from porphyry gneisses into sedimentary rocks, which he had seen in 1923 and which bears no close resemblance to an igneous contact.

GRADATION FROM PORPHYRY INTO MIGMATITE GRANITE

About 6 miles northeast of Killarney village is the southern end and outlet of George Lake. This end of the lake, which may be known as Tyson Bay, is a narrow bay elongated in the direction of the strike of the rocks. The contact between coarse and fine gneisses passes near the northwestern shore of this bay. On the shores of this bay recognizable Gowanda formation, including laminated graywackes and conglomerates, grades into fine-grained, stony, porphyritic gneiss. The porphyritic gneiss grades into a medium-grained microcline-rich gneiss, which is apparently the same as the rock low in ferromagnesian minerals noted by Jones (1930, p. 48). This kind of rock was found also near the transition from coarse Killarney granite to fine porphyry gneiss about half a mile southwest of Tyson Bay, again on the north shore of the bay, and about 300 feet east of the strait, in the same relative geological position.

NATURE OF MIGMATITE GRANITE

General statement.—This type of rock is common in the gneisses of Georgian Bay localities and has been described frequently in sections of

the writer's report to the Geological Survey of Canada. In some places it is so-called "giant-granite", elsewhere it is an alaskitic gneiss referred to generally as "fine, dense, pink gneiss", and everywhere it has a massive granulitic texture and a high proportion of microcline and a low content of ferromagnesian minerals. Such a rock is the famous Hängo granite of Finland, which is called variously a microcline granite, a metasomatic granite, and a migmatite granite by Wegmann and Kranck (1931, p. 87-89). However, in Finland this type of rock covers many hundreds of square kilometers. Migmatite granite development must therefore be recognized as a major metamorphic process (Quirke, 1927, p. 755-770). Apparently it has been widely operative in the Killarney and other areas about Georgian Bay, and without its recognition the fundamental geological relations of the various rock formations cannot be unraveled. This rock is fundamentally metamorphic as its "blastic" or granulitic texture testifies. On the other hand its composition is that of a granite very high in microcline and low in ferromagnesian minerals. It suffers internal deformation by means of granulitic reconstruction and reveals invasive contacts with other rocks; consequently it looks like an intrusive igneous rock in the field.

Transitional position of migmatite granite.—The recognition of this type of rock in the transition or contact zone between the coarse Killarney granite and the fine porphyritic gneiss is important and will be described in some detail; it is indicated on the accompanying sketch map (Fig. 2).

West and northwest of the crossroads from Tyson Lake to the Tyson farms the fine porphyritic gneiss of Killarney inlet is apparently closely associated with quartzitic looking gneisses along the strike, includes zones of coarse, red gneiss, and is separated from the Killarney granite proper by a strip of microcline granite. In a general way the geological relations are like those described by Jones (1931, p. 48) in the transition zone east of Killarney Bay.

Contact between migmatite and granite.—Microcline granulitic gneiss was found also between the sedimentary rocks and porphyritic fine gneisses and the Killarney granite gneiss on the north side of Tyson Bay of George Lake. Special pains were taken to determine the geological relations in that place where exposures are excellent. Joining George Lake to Tyson Bay a narrow strait nearly half a mile long cuts across the Killarney granite gneiss. The contact between Killarney granite and microcline gneiss crosses the strait near its southern end. East of the strait the line of contact may be followed in a northeasterly direction. The contact is sharp, not easily seen because of the similarity of the rocks in contact, but quite recognizable. The coarse gneiss is typical pink

Killarney granite in this place, medium-grained, with feldspars as large as 6 mm. in diameter and biotite in subparallel lenses, which give a gneissic appearance to the rock. The granite includes lenses or strips of pink aplitic rock, the largest observed of which is about 5 feet wide

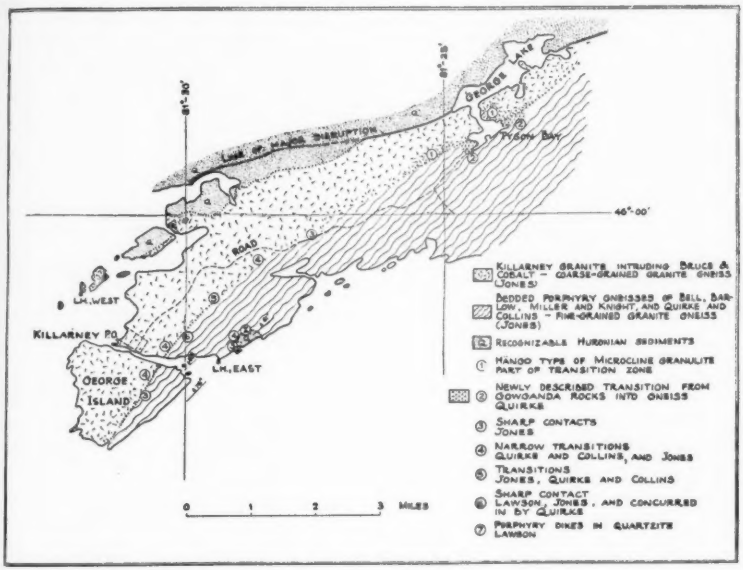
81°-30'
81°-30'
GEORGE LAKE
LINE OF MAGNETIC DISRUPTION
PIGEON BAY
46°-00'
ROAD
LM. WEST
KILLARNEY PO.
LM. EAST
GEORGE ISLAND
KILLARNEY GRANITE INTRUDING BRUCE & COBALT - COARSE-GRAINED GRANITE GNEISS (JONES)
BEDDED PORPHYRY GNEISSES OF BELL, BARLOW, MILLER AND KNIGHT, AND QUIRKE AND COLLINS - FINE-GRAINED GRANITE GNEISS (JONES)
RECOGNIZABLE HURONIAN SEDIMENTS
HANOO TYPE OF MICROCLINE GRANULITE PART OF TRANSITION ZONE
NEWLY DESCRIBED TRANSITION FROM GOWGANDA ROCKS INTO GNEISS QUIRKE
SHARP CONTACTS JONES
NARROW TRANSITIONS QUIRKE AND COLLINS, AND JONES
TRANSITIONS JONES, QUIRKE AND COLLINS
SHARP CONTACT LAWSON, JONES, AND CONCURRED IN BY QUIRKE
PORPHYRY DIKES IN QUARTZITE LAWSON
0 1 2 3 MILES

FIGURE 2.—*Geologic sketch map of Killarney and George Lake*

and 100 feet long. The size of grain in these aplitic layers varies somewhat; the feldspars are 2 mm. in diameter in some and smaller in others. None of these aplitic layers has a stony or felsitic texture. The rock contains a small amount of biotite arranged in very indefinite lines. Within 2 feet of the contact the granite is dark red, apparently due to a slight concentration of biotite near the fine pink gneiss; as the contact is approached the texture becomes more granitic, the grain finer, and the color darker. On the other hand the fine pink gneiss appears to be of the same composition, grain, and texture right up to the contact. There are layers of fine pink gneiss in the granite and lenses or bands of granite within the pink gneiss; all are parallel to the general structure of the rocks. Neither rock appears to send dikes or other transgressive members into the other.

GRADATION FROM PORPHYRY INTO SEDIMENTARY ROCKS

Relations between porphyry and muscovite schists.—At and near the shores of Tyson Bay the stony porphyritic gneiss is associated with remnants of sedimentary rocks, as near Killarney. The well-bedded, porphyritic gneiss extends uninterrupted from George Island to George Lake. Within this gneiss are layers of porphyritic gneiss some of which contain quartz and others feldspar phenocrysts, both sheared and unsheared. There is also muscovite-bearing rock both in layers and in irregular patches which the writer has always taken to be residuals of sedimentary rocks. Such muscovite inclusions or remnants are common in the well-bedded, stony, porphyritic gneiss near George Lake, especially on the first headland north of the dam on Tyson Bay. Spidery irregular shapes of muscovite gneiss within the denser porphyritic gneiss indicate the degree to which the original sediments, metamorphosed into muscovite schists, have been replaced by further metamorphism in places into a feldspathic gneiss.

Feldspar phenocrysts younger than schistosity.—Near-by are bands or layers of muscovite schist within the well-bedded feldspar porphyry gneiss. From some of these exposures the observer might question whether the muscovite schist layers may not be severely sheared portions of the bordering, less fissile porphyry gneiss. It is obvious, however, that near Killarney east lighthouse the muscovite schist is derived from sheared quartzite, and near George Lake feldspar metacrysts in muscovite schist and in fine porphyritic gneiss alike show clearly that feldspar phanerocrysts developed later than the muscovite schistosity. The porphyry near George Lake differs somewhat from that near Killarney in displaying much less internal homogeneity; the irregularities are accentuated by weathering on inland exposures more than on the fresh scoured surfaces near Georgian Bay. Near George Lake, chips or sliver-like remnants of muscovite schist are very common in the fine porphyry gneiss, as well as certain transverse muscovite streaks which apparently record the position of joints in the sedimentary rock now converted into porphyry gneiss.

On the first and second points north of the dam in the southwestern part of Tyson Bay, muscovite schist layers contain the crushed remnants of either pebbles or brecciated pieces of rock. They are very much flattened in a plane parallel to the bedding. It is within these muscovite and porphyritic bands that well-formed feldspar metacrysts spot almost equally the solid, dense, pink parts and the leaf-like, fissile muscovite schist. The banded character of the rocks is very striking on the northern side and near the center of the southern point.

FIGURE 1. SPIDERY, IRREGULAR SHAPES OF PALE MUSCOVITE GNEISS
Within the denser porphyritic gneiss. On the southwest side of Tyson Bay, George Lake.

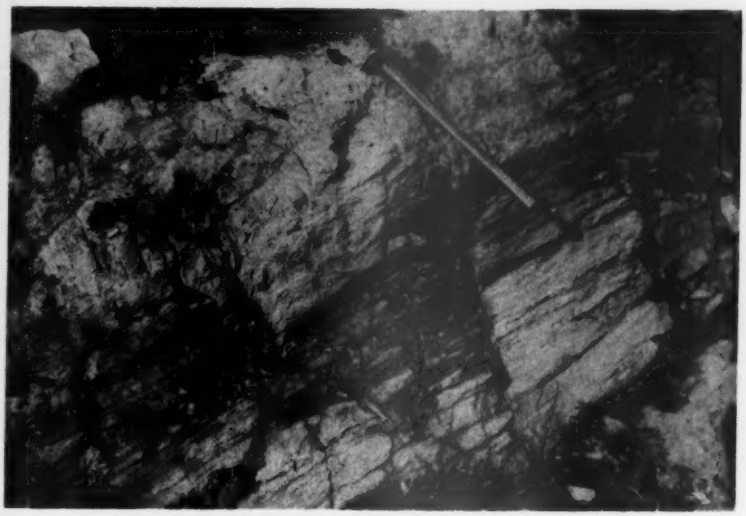

FIGURE 2. BANDS OR LAYERS OF MUSCOVITE SCHIST
Within well-bedded feldspar porphyry gneiss. Both schist and gneiss are spotted with feldspar phenocrysts or metacrysts. On the southwest side of Tyson Bay, George Lake.

METAMORPHIC TRANSITIONS

FIGURE 1. CONGLOMERATE WITH GRAYWACKE MATRIX AND PEBBLES OF VARIOUS COMPOSITION
Feldspar metacrysts have developed in both pebbles and matrix. Northeast shore of Tyson Bay, George Lake.

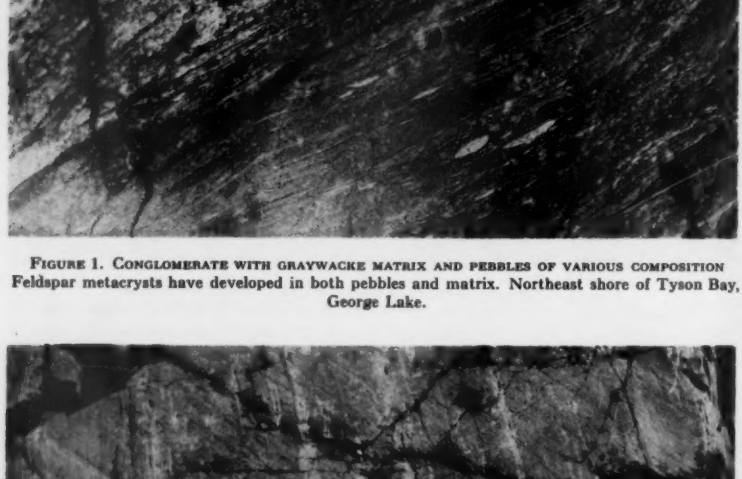

FIGURE 2. THINLY LAMINATED GRAYWACKE CONTAINING MANY SMALL PEBBLES AND OCCASIONAL LARGE ONES, ALL SHEARED OUT
This graywacke grades into fine dense porphyritic gneiss like that at Killarney. About 150 feet south of the outcrop illustrated in Figure 1.

PORPHYROBLASTS IN CONGLOMERATE

GRADATION FROM PORPHYRY INTO GOWGANDA CONGLOMERATES

The relations between porphyritic rock and sedimentary rocks are well shown also near the northeastern corner of Tyson Bay. On the south side of the fine pink gneiss, previously described, is an outcrop of conglomerate with graywacke matrix and pebbles of various composition. In both pebbles and matrix feldspar metacrysts have developed to varying extent. Some of the graywacke matrix is spotted sparsely with large feldspars, and other parts are closely spotted with small ones. Most of the pebbles are greatly flattened, some being several feet long, and the majority much less than a foot wide. Most appear to have originally been granite. In hand specimens the matrix of parts of this conglomerate looks much like the fine porphyritic gneiss. South across the strike 35 feet from the rocks last described the rocks are typical Gowganda laminated graywacke with occasional pebbles scattered along the bedding. Here the original character of the rock is little disguised by metamorphism, and the rock can easily be recognized as of the Gowganda formation. No other formation near the north shore of Lake Huron is known to carry pebbles scattered irregularly through a thinly layered "slaty" matrix. Nevertheless, this is evidently the rock which shears down in this locality to a muscovite schist, the layers of different composition naturally giving rise to different streaks in the metamorphic equivalents. From the various layers in this exposure of Gowganda formation there are numerous examples of incipient or complete porphyritic gneiss.

At a distance of 150 feet south from the last point, there are exposures of thinly laminated graywacke containing pebbles. Most of the pebbles are about 2 inches in diameter, measured along their direction of flattening, but some of the pebbles maintain their nearly spherical shape.

There are also 3- to 6-foot bands of thickly set pebbles. One of these streaks composed only of small pebbles has the appearance of a granite dike parallel to the bedding of the graywacke. Different layers of this graywacke-conglomerate formation show different degrees of metamorphism, but in spite of that the sedimentary nature of the whole outcrop cannot really be in doubt. Some of the laminated graywacke is so dense that it looks like chert on broken faces and probably is incipient porphyry gneiss. A few feet farther south across the strike is an area of stony, nearly massive porphyry gneiss, some of which contains quartz phanerocrysts, some feldspar, and other both quartz and feldspar phanerocrysts. Almost every variety of the fine dense porphyritic gneiss may be duplicated in the partly altered beds of the unmistakable sedimentary conglomerate rocks of the immediate vicinity.

ANALYSES OF TRANSITION ROCKS

Two Rosiwal analyses of some of the transition rocks are as follows:

Rocks from George Lake

Rosiwal analyses by volumes

	1	2
Quartz	58	40
Orthoclase	40	
Microcline		55
Oligoclase		4
Hornblende	2	
Magnetite		1

CLASSIFICATION OF TRANSITION ROCK TYPES

Analysis No. 1 corresponds to a specimen of fine-grained felsitic-looking rock, which contains phanerocrysts of orthoclase and rounded grains of quartz which look like phenocrysts. The matrix of the rock is very fine grained, but varies in grain size even in the fine matrix. It maintains the appearance of internal lamination, like that due to bedding. It outcrops on the southwest side of Tyson Bay, near George Lake. It appears to grade both into bedded muscovite schist and into granitic rock. It seems to the writer to be almost exactly the same sort of thing as the so-called "porphyry" at Killarney. If Johannsen's rock classification is applied to this analysis it falls with the greisen type of rocks, specifically as quartz-leuco-orthogranite, 103.

The rock corresponding to analysis No. 2 is found in fine, dense, pink lenses, but not dikes, within the Killarney granite north of the northeast end of Tyson Bay near the contact, or transition, between the Killarney granite and the Gowganda formation. This rock also belongs with the greisen group. It is classified as granite-greisen, 122. It is notable for its high content of quartz and microcline and approaches very closely in composition and texture a form of replacement intrusion, like the famous Hängo granite. In this connection it seems worth while to revive a topic already treated somewhat fully in earlier American literature. Winchell (1901-1902, p. 522-525) points out that secondary growths of feldspar may be so much extended that they form a granitic texture in the rock.

> "The rock thus passes to a normal granite or diorite or other massif, according to the mineral composition. . . . This regrowth of feldspar is apparent, so far as examined by the writer, in nearly all the metamorphic and massive acid rocks."

Similar notes are recorded by Van Hise (1898, p. 88-89), Whittle (1893, p. 147), and Hobbs (1893, p. 167). Wolff (1891, p. 171-185) has published excellent photomicrographs, very similar to those of Jones and Quirke, which were interpreted by Wolff essentially as they would be by Quirke.

SUMMARY AND CONCLUSIONS

From the neighborhood of George Lake, about 6 miles from Killarney, relations between the Gowganda formation and porphyry gneiss duplicate the relations at Killarney between Lorrain quarzite and porphyritic gneiss. In both localities it appears to the writer and his associates that the rocks grade into each other and that the porphyritic gneiss is a highly altered sedimentary rock. Near George Lake the porphyritic gneiss grades also into a fine, dense, pink gneiss which looks like a plutonic igneous rock. The contact between Killarney granite and the other rocks is in most places ambiguous. To the writer the granite appears to be the youngest rock of the district, in spite of local appearance of gradation into the fine, stony, porphyry gneiss and the intervening position of the fine, dense, pink gneiss (migmatite). In any case the intrusive nature of the Killarney granite is abundantly borne out by evidence revealed along the contact line between Killarney Bay and Wavy Lake. The evidence from Killarney that the fine porphyritic gneiss is composed of metamorphosed sedimentary rocks and not an igneous rock at all in the ordinary sense of the word is confirmed by the relations near George Lake. The rock which appeared to the writer to form the link between the Killarney granite and the porphyritic gneiss of metamorphic sedimentary origin is now recognized as distinct from the Killarney granite proper and as a still more advanced product of metamorphism than is the porphyry gneiss. It is considered to be a true migmatite, of the composition of microcline granite, like the Hängo granite of Finland. It appears to be the most pronounced phase in the metamorphic series of (1) Quartzite or graywacke, (2) muscovite schist, (3) porphyritic fine gneiss, (4) microcline-rich granulitic gneiss, migmatite, or fine, dense, pink gneiss.

The final product of metamorphism (migmatite) is very like a plutonic igneous rock, and the porphyritic fine gneiss has been pronounced an intrusive, truly igneous rock by Jones and Lawson. Following generally accepted definitions, the writer recognizes that no degree of metamorphism, short of actual fusion, can give rise to true igneous rocks. It is his belief that these rocks have been converted by metamorphism, by the action of physical and chemical influences upon solid rocks, and that they cannot be truly igneous rocks regardless of their structure, texture, and mineral and chemical composition. Finally in response to the conclusions of Jones and Lawson that the fine porphyritic gneiss is an intrusive rock he would note the following facts. The mass of rock so mapped is at least 8 miles long and over a mile wide. It is of fine, nearly uniform

grain and composition throughout. It shows no progressive decrease in size of grain toward either the east or west borders, except for the very narrow selvedge (less than 2 inches wide) described by Jones and Lawson as a chilled edge, and interpreted by the writer as a small mylonized shear zone. In spite of its great size for an injection (as postulated by Jones and Lawson) it is very fine-grained even in the center of the mass. If it had been chilled at the edge as claimed by Jones and Lawson, it must have been liquid enough at the time of injection to have given off very fine, even glassy veinlets. Such have not been found anywhere near this mass by the writer in spite of extensive search. Local veinlets of aplitic and porphyritic types less than an inch wide show no such chilling or glassy texture. On the other hand the advanced metamorphism of a rock formation so uniform in composition as the Lorrain quartzite might be expected to produce a rock uniform throughout both in texture and composition. Finally, no igneous injection a mile thick and 8 miles long can by any geological theory be supposed to display throughout its mass a nearly vertical structure like that of a bedded rock formation. It would be a strange coincidence indeed if such an exceptional igneous structure should be in accordance with the bedding structures, not only of sedimentary formation along and across the strike from its own structure, but even of those masses "engulfed" within it. In spite of the contributions of Jones and Lawson the writer cannot abandon the conclusion (Quirke and Collins, 1930) that the fine porphyritic gneiss is a highly metamorphosed quartzitic rock, but he does recognize that the gradation from fine porphyritic gneiss into massive granitic rock (migmatite) may better be classed as a metamorphic change rather than an igneous change, and that the intrusion of Killarney granite proper in places is distinct from both the porphyritic gneiss and its migmatitic granitic equivalents.

This group of intrusive rocks—dikes, sills, and ill-defined masses known collectively as the Killarney "granites"—represents more than one episode of intrusion. The geologic age of those rocks first known at Killarney, Ontario, as Killarnean is thus inclusive of a considerable duration of time. The remarks of Lane (1935, p. 60-61) as to the different ages of various intrusive rocks called Killarnean are as pertinent to the intrusive rocks near the original locality as to others. The writer hopes in the near future to be able to present a classification of the rocks in Ontario which have been mapped as Killarnean and to show the extent to which such rocks differ in class, in structure, and in age.

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University of Illinois, Urbana, Illinois

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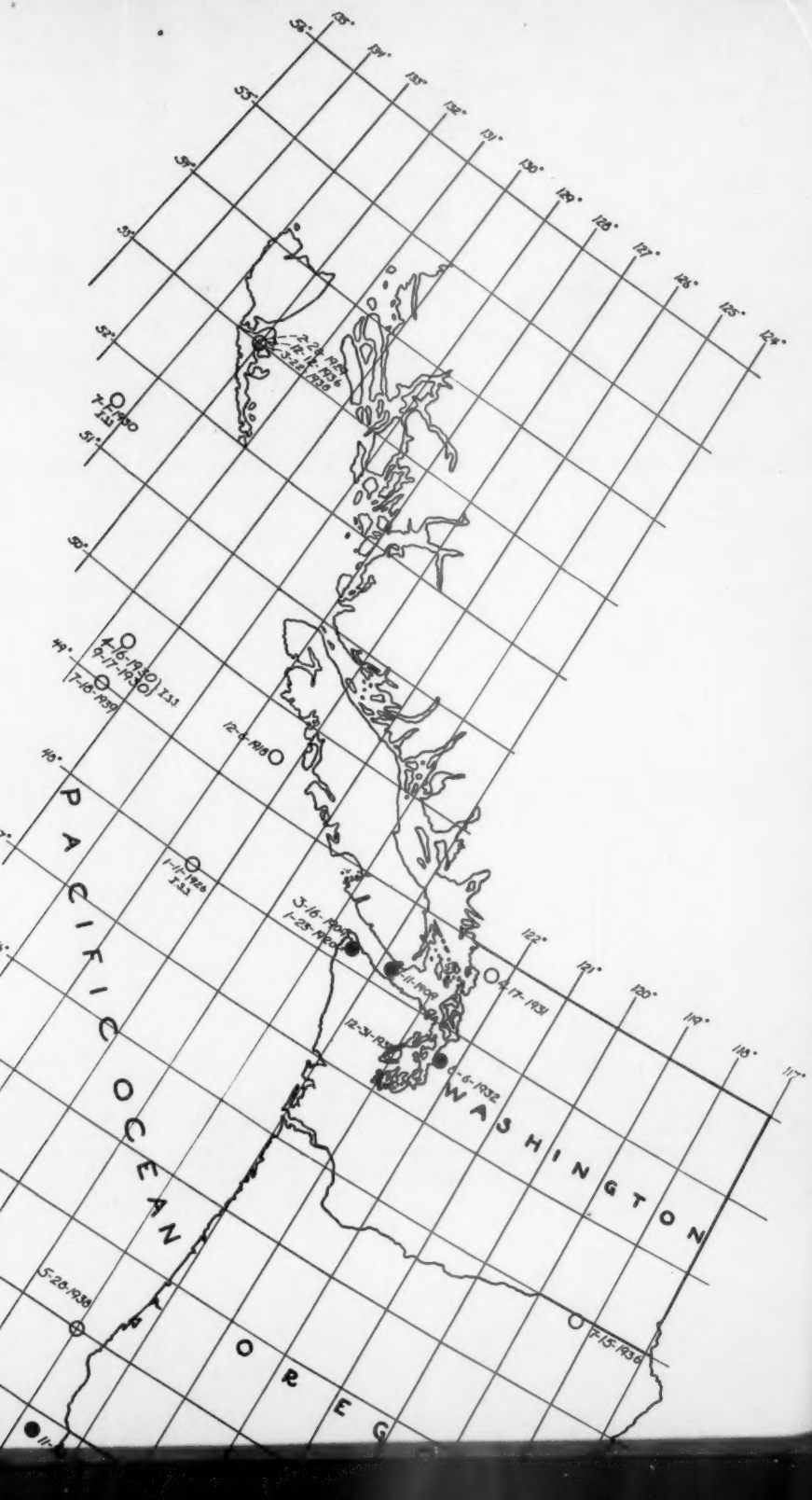
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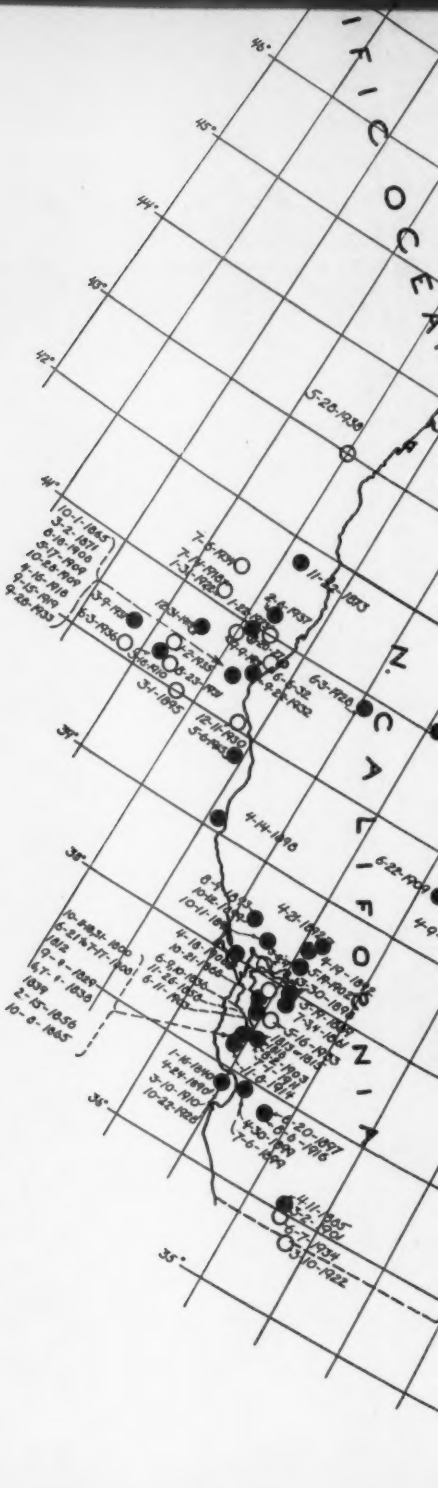

EPICENTERS OF STRONG E

Solid circles represent epicenters based on

STRONG EARTHQUAKES OF THE NORTHERN PACIFIC COAST.

rs based on field data; open circles represent those located by instrumental data.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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SEISMICITY OF THE NORTHERN PACIFIC COAST OF THE UNITED STATES

BY PERRY BYERLY

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ABSTRACT

A map is presented showing the epicenters of strong earthquakes, the earlier ones being located from field data obtained from the *Descriptive catalog of earthquakes of the Pacific Coast of the United States, 1769 to 1928,* and the later from instrumental data. Some general conclusions are suggested from the distribution of these epicenters. The seismicity of groups of counties in northern California is rated on an arbitrary scale. The seismicities are presented in the form of a map.

INTRODUCTION

The appearance of the *Descriptive catalog of earthquakes of the Pacific Coast of the United States, 1769 to 1928,* by Townley and Allen (1939) has made it a simpler matter to summarize the earthquakes of the region involved in this study. Although the University of California seismographic station was established in 1885, it was not until 1911 that instruments as modern as the Bosch-Omori were put into operation. In 1922 the Victoria station was equipped with Milne-Shaw seismographs (before this it had Milnes). In 1909 a small Wiechert seismograph was installed at Spokane. This was in operation until recently when it was moved to Mount St. Michaels. Reports have not always been issued at this station, and time service was not always reliable. Before 1922 instrumental locations of moderate-sized shocks in the northern part of California, in particular the large number occurring off the coast of Humboldt

County, were not often possible. Even after Victoria records were available epicenters could not be located very accurately as control from the east was lacking unless the shock was large enough to record well at St. Louis or Chicago. The establishment of a station at Bozeman in May 1931 offered additional control for many of the shocks, and finally the opening of the Ferndale station in January 1933 made such locations reasonably accurate. Between 1911 and 1931 there were available for the location of the smaller central California shocks only the seismograms from Mount Hamilton and Berkeley. In 1931 the addition of a station at Palo Alto increased the group which now includes also San Francisco, Ferndale, Fresno, and Mineral. The records from the Pasadena group of stations are also available now for location of the larger shocks.

EPICENTERS

In preparing maps of epicentral locations it is therefore necessary to approximate locations for the earlier days from the field data available. On the map (Pl. 1) are plotted the epicenters of all the larger shocks on record in Washington, Oregon, and California north of San Luis Obispo, Kern, and San Bernardino counties, as well as those off the coast of British Columbia. By larger shocks are meant those strong enough to crack walls and cause chimneys to fall. Some of the earthquakes centering off the coast were included from the magnitude of the seismograms or from the large area feeling the shock on shore rather than on the basis of the criterion of damage to buildings, since this is not applicable to centers far at sea. The date of the earthquake is given with each epicenter on the map. Field data came from the earthquake catalog (Townley and Allen, 1939) and from the publication *United States earthquakes* of the United States Coast and Geodetic Survey.

Only those instrumental epicentral locations are entered on the map for which there were good data available, and the locations are reasonably accurate. They do not include many epicenters listed in the early issues of the *International summary*. The inclusion of doubtful locations would only serve to mask any geologic significance of the distribution. The data on which epicenters so rejected were based have been examined in each case, and all the rejections would probably be approved by any seismologist; 15 epicenters off the coast of California and 26 farther north have been so rejected.

The most seismic regions in the area mapped are the one about San Francisco Bay and the one just off the coast of Humboldt County. These lie in the more persistent fault zones of the Coast Ranges and their seaward extensions. It is noteworthy that epicenters practically cease at 42° N. and begin again off the coast of Canada. It is suggested that

the San Andreas Fault zone reaches the border of the continental mass near 42° N. 126° W. and that the stresses leading to earthquakes, which are common on the continent, do not persist in the oceanic floor.

Another zone of epicenters along the Sierra roughly parallels that just discussed. The only epicenter at sea off the Oregon coast lies roughly on an extension of this zone.

The lack of epicenters off the central California coast south of the Humboldt County zone is remarkable. It is only considerably farther south off Santa Barbara County that a zone of activity is again found off the coast, and this again is in the general region which is an extension to sea of a zone of activity on land. This zone runs roughly east-west. There again the lack of transfer of stresses into the ocean basin is suggested by the fact that those epicenters do not persist far from land.

The seismic quiet of Oregon and Washington is marked. The few shocks about Puget Sound were just large enough to come within the classification stated, but they were not large shocks. Off the coast of Vancouver Island there again begins a zone where larger shocks are not uncommon.

SEISMICITY

On Figure 1 the counties of northern and central California are divided into groups for the purpose of rating seismicity. Only earthquakes reported felt since 1850 were included. This beginning date was adopted because earlier reports from all parts of the region were not available. An effort was made to exclude aftershocks. After a large earthquake the vast number of small shocks was neglected for a period of 1 to 3 months until the number occurring at least approached the number observed before the main shock.

On the map, the three hyphenated numbers represent the number of earthquakes reported in the three following categories: (1) All shocks up to those of sufficient intensity to rattle doors and windows but not disturb movable objects; (2) those which disturbed movable objects or overthrew them, cracked plaster but did not damage masonry; and (3) those strong enough to damage masonry.

Below the three hyphenated numbers appears a third number which is the seismicity of the area. It was obtained from those above as follows: Earthquakes of the first type listed above were weighted 1, those of type two were weighted 5, those of type three were divided into two kinds. Those not accompanied by surface faulting were weighted 25, while the three great shocks during the period in question which were accompanied by faulting were weighted 125. The great earthquake of April 18, 1906, was assigned equally to all the groups of counties within

whose area it was accompanied by surface fault break. The number of shocks in each category was multiplied by the weight, and all were added for each group of counties. The resulting figure was divided by the area of the region. The numbers then obtained were in ratio to the

FIGURE 1.—*Seismicity of northern California*

seismicities listed, the seismicity of the San Francisco Bay region being taken arbitrarily as 10.

There is no doubt that the group of counties about San Francisco Bay is the most seismic, but it was surprising to the writer that the Humboldt-Del Norte group did not show a larger figure in comparison, since of late years it has had many more large shocks than the San Francisco Bay region. Its seismicity moreover includes a number of shocks centering at sea.

It must be remembered that earthquakes are more accurately reported in some regions than in others, and that such will undoubtedly affect the rated seismicity. However, the system of heavily weighting the stronger

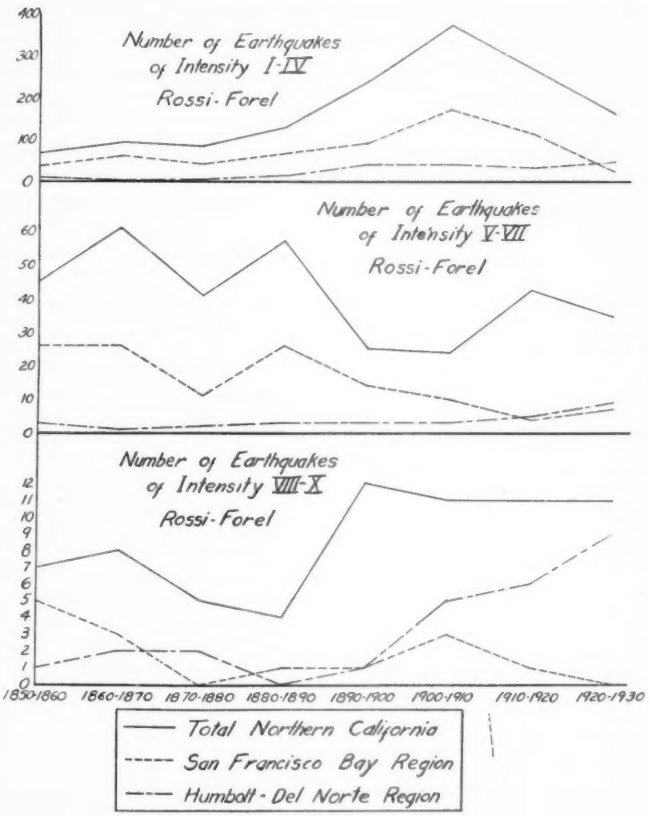

FIGURE 2.—*Frequency of earthquakes*

shocks should help to counteract this, since it is only for the smaller shocks that failure to report should be an important factor.

We see the presence of Mount Lassen reflected in the seismicity for the Trinity-Lassen-Shasta group, and the seismic zone noticeable today in Plumas County reflected in the seismicity of the group including that county.

The comparative quiescence of the counties between the Golden Gate and Humboldt County so marked today shows in the seismicity figures. It is to be noted that it was in Marin County that the greatest fault displacement was observed in 1906. It appears that in this region and possibly in the region of the center of the Fort Tejon earthquake (1857) farther south there is greater effective friction along the San Andreas Fault which prevents many small shocks and saves the accumulating strain for larger displacements. Perhaps we have here regions of greater pressure transverse to the fault.

Figure 2 shows the distribution in time of earthquakes in three areas—the San Francisco Bay counties, the Humboldt Bay counties, and northern California as a whole. The number of shocks are plotted for 10-year periods.

WORK TO WHICH REFERENCE IS MADE

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INVERTEBRATE FAUNA OF THE LATE PERMIAN WHITEHORSE SANDSTONE

BY NORMAN D. NEWELL

(With descriptions of fossils by J. Brookes Knight, Raymond C. Moore, and Kenneth G. Brill, Jr.)

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ABSTRACT

The Whitehorse fauna occurs high in the red beds section of the Mid-continent region near the Paleozoic-Mesozoic boundary. Underlain and overlain by a great thickness of nearly unfossiliferous rocks this fauna occupies a key position for the correlation of a part of the red beds. Although composed dominantly of pelecypods and gastropods the fauna also contains bryozoans, serpulids, and brachiopods. The fossils occur as molds in very long, narrow sandstone and dolomite lenses interpreted here as marine offshore bars. There are 32 species recognized, of which 7 are described as new. They are distributed among 29 genera, of which 6 are presented as new. Pertinent stratigraphic and faunal evidence bearing on the age of the Whitehorse fauna is marshaled, resulting in the conclusion that it is late Permian in age, probably correlative with the Capitan fauna of the standard Permian section in western Texas. The possibility is recognized that the Whitehorse fauna may be slightly younger or older than the Capitan.

STRATIGRAPHIC AND FAUNAL SUMMARY

STATEMENT OF THE PROBLEM

The late Paleozoic sequence in the Mid-continent region of the United States includes one of the best-known sections of Pennsylvanian and Permian rocks. The Pennsylvanian and lower Permian rocks are richly fossiliferous, being almost unparalleled in the large number of persistent faunal and floral zones. At the top of the fossiliferous part of the section is a thick succession of red beds containing considerable dolomite, gypsum, anhydrite, and salt. These red beds are almost completely barren of fossils except for an invertebrate fauna in the Whitehorse sandstone, near the top, and a few terrestrial vertebrates near the bottom of the section. In Kansas and Nebraska the red beds have been included in the Cimarron series, loosely referred to the "Upper" Permian. In Oklahoma equivalent strata have been placed in three divisions: Wanette, Minco, and "Custer." The Texas equivalents comprise Wichita to Double Mountain (Custer) strata, inclusive. The red beds are overlain in Oklahoma and Texas by variegated continental beds of late Triassic age—the Dockum group—and

grade downward into the gray *Pseudoschwagerina*-bearing Big Blue series and equivalents, commonly designated as earliest Permian.

In recent years the location of the Paleozoic-Mesozoic boundary in the Mid-continent region has been debated. The oldest undoubted Triassic rocks are referred to the upper Triassic. Many geologists hold to the opinion that part of the red beds may be early or medial Triassic in age.

A fauna of marine invertebrates occurs in the Whitehorse sandstone, high in the red beds, occupying a thin zone in otherwise unfossiliferous rocks. This fauna is of more than ordinary interest because of the bearing that it has on the age relationships of the upper red beds. The purpose of this study has been to discover the age of the Whitehorse fauna and to adequately describe the fauna.

PREVIOUS WORK AND IDEAS

In 1900, Van Vleet and Gould discovered invertebrate fossils high in the red beds section of northwestern Oklahoma; these, together with other collections from about the same horizon in northern Texas, were described by Beede (1902; 1907), who commented on the unusual facies of the fauna and assigned it to the late Permian. Beede (1910) later recognized certain species of this fauna in poorly preserved pelecypods and gastropods from the Carlsbad limestone near Lakewood, New Mexico. Since the Carlsbad was generally regarded as late Permian, Beede cited his discovery as contributory evidence for the late Permian age of his red beds fauna.

Beede thought that his collections from northwestern Texas were from a higher horizon (Quartermaster) than his Oklahoma material (Whitehorse), but work by Clifton (1926), confirmed by Roth (1932), indicated that these occurrences of marine fossils in the upper red beds do not vary greatly in stratigraphic position but all lie in that part of the column generally known as the Whitehorse sandstone.

The Whitehorse sandstone, with its unique fauna, is delimited at the base by a regional unconformity (Roth, 1937; Brown, 1937) and appears to be lithologically more closely related to succeeding strata up to the base of the late Triassic Dockum beds than to underlying rocks. Accordingly these upper red beds containing the fossils in the lower part, were regarded as a stratigraphic unit by Roth (1932; 1937), and to this unit he has applied the term Custer.

As the "Custer" group appears to be lithologically somewhat distinct from older red beds and is overlain by late Triassic rocks, Roth has suggested that the "Custer," including the Whitehorse sandstone at the base, may be early or medial Triassic rather than late Permian as suggested by Beede.

There is a current tendency to reject Roth's "Custer" group on the grounds that it is not a natural lithologic unit. Without wishing to champion the "Custer" group, the writers have found the use of the term "Custer" a convenient one for purposes of the following discussion.

PRESENT INVESTIGATION

The Whitehorse fauna, situated as it is in the midst of unfossiliferous strata near the Paleozoic-Mesozoic boundary, has more than ordinary significance in the taxonomy and correlation of the upper red beds in the Mid-continent region. The present study is a natural outgrowth of the writers' special interest in stratigraphic and paleontologic problems of the late Paleozoic.

Three collections of Whitehorse fossils were available for our study. One of these is the Beede collection of type specimens located at the University of Kansas. Although many of Beede's original types of Whitehorse fossils were destroyed or lost before being brought to the University of Kansas, some of the primary types and many "neotypes" are still extant in the Beede collection. The second collection consists of many hundreds of specimens collected by the senior author with the aid of a grant from the Penrose Bequest of The Geological Society of America. This collection has been divided among the geological museums at Princeton University, University of Kansas, and the University of Wisconsin. The third collection was made independently by Robert Roth and now resides in the Peabody Museum, Yale University.

Study of the Whitehorse fauna was originally undertaken independently by Newell and Brill. Later they decided to collaborate in the work, finally calling on the assistance of Knight and Moore. The final plan of the investigation has been to divide the fauna biologically into four groups, each group being assigned to one of the collaborators. The general summary and synthesis has been assumed by Newell.

ACKNOWLEDGMENTS

Financial assistance for collecting fossils was received by the first author from the Penrose Bequest of The Geological Society of America, and he received aid for the completion of part of the research from the fund for graduate research at the University of Wisconsin. A large collection of Whitehorse fossils collected by Robert Roth and presented to the Peabody Museum at Yale University was made available by Dr. Carl O. Dunbar. Mr. N. W. Bass contributed a small collection of Whitehorse fossils from the Verden lens of western Oklahoma. During the progress of this study constructive criticism was given by Dr. P. B. King, Mr. R. K. DeFord, Mr. John E. Adams, Mr. John Skinner, and

Mr. Robert Roth. The writers are also indebted to the late Dr. George H. Girty of the U. S. Geological Survey for help and advice on certain points and for the privilege of studying the types of some of his Guadalupian species with which some of the Whitehorse forms seem to be comparable. He was also kind enough to hurry the publication of his new gastropod generic name, *Taosia*, so that it could be employed here.

OCCURRENCE OF WHITEHORSE FAUNA

At certain horizons within the Whitehorse sandstone invertebrates are exceedingly abundant, and belong chiefly to a few species of pelecypods and gastropods. The specimens are almost invariably preserved as molds in dolomitic sandstone or sandy dolomite. The rock in which they occur is generally cross-bedded and is relatively resistant to erosion so that the fossiliferous beds are commonly conspicuously exposed near the top of buttes and escarpments. The fossiliferous deposits occur in elongate, nearly straight, and relatively narrow lenses of the type commonly called "shoestring" sands, or "channel sands." These lenses are ordinarily 10 to 40 feet thick, less than half a mile broad, and several miles long, in a direction parallel to the regional strike of the beds. The Dozier lens, however, is exceptional in being at least 12 miles wide. It is relatively long, extending from Wheeler to Dickens County, Texas.

For some years an idea was favored by some geologists that these fossiliferous lenses represented channel fillings of stream valleys, in which shells of marine invertebrates had in some fashion been deposited, either more or less *in situ* within drowned river valleys or by being transported by currents from a marine environment into a fresh-water environment (Reeves, 1922, p. 61; Reed and Meland, 1924, p. 164-167). More satisfying is the interpretation by Bass (1938; 1939) that many of these "shoestring sands" are offshore barrier bars, differing markedly from stream deposits in their straight and unbranched trends and in the relatively uniform, unidirectional bedding. Brown (1937, p. 1544) and Sawyer (1924, p. 312-321) came to somewhat similar conclusions.

It should be noted that although a considerable proportion of the Whitehorse brachiopods and pelecypods examined are in the bivalved condition, and commonly show no evidence of considerable wear, many others are abraded, though rarely broken.

Certain features of the "shoestring" deposits in the Whitehorse sandstone have long defied satisfactory explanation. Practically all the fossils in the Whitehorse occur in these deposits. Shales and sandstones which are the lateral equivalents of the linear deposits or which lie above or below them are barren of fossils, yet the rocks are of types in which fossils might be preserved. The sandstones of these lenses are every-

where dolomitic. In most places the dolomite firmly cements the sandstone, but in some places, usually at the base of the deposit, the rock is a nearly pure dolomite, which is generally oölitic. The fossils found in the more dolomitic phases show the least signs of wear, and unseparated bivalved shells are the rule, whereas upper, sandier layers contain shells in which the two valves generally are separated.

In several places fragile ramose Bryozoa were observed in the basal dolomite beds of the linear deposits. In some instances relatively large fronds with hundreds of branches were observed, some apparently in position of growth. It is evident that such specimens could not have been transported intact but simply were buried by the advancing sand of migrating bars. Bryozoa occurring in the upper part of these deposits invariably are fragmentary, as though they had been broken and transported before burial.

In connection with the present study of the Whitehorse Bryozoa Moore notes that

"thin sections show that round oölite grains are rather common in the matrix surrounding some of the bryozoans. The oölites are probably formed by calcareous algae. At all events, they suggest comparison with the very common oölitic or algal limestone association with abundant bryozoans in many cyclothems of the Pennsylvanian section of Kansas. This simply means that bryozoans, along with various mollusks and a few brachiopods, are elsewhere observed to thrive in an environment that produced oölitic material as the dominant element in the surrounding sediments. An interesting feature of the sandy sediments that contain the bryozoans is their average very fine grain, about 0.10 to 0.15 mm. in diameter of the quartz grains, associated with sporadic occurrence of large, very well rounded quartz grains that measure 0.5 to 0.7 mm. in diameter, and with calcareous and dolomitic matrix. Most of the specimens containing bryozoans effervesce vigorously when treated with acid. The common color is an orange red, in many cases mottled with very light gray; a few specimens are mostly light gray."

The matrix enclosing the fossils consists generally of friable to hard, red and pink sandstone, the grains of which commonly exhibit a matte surface and excellent rounding. Locally the basal layers of the fossiliferous deposits grade into pink or red dense dolomite in which the best preserved fossils are found.

As commonly is the case with dolomitic rocks the molluscan shells are preserved as internal and external molds. A very few of the brachiopod and bryozoan specimens retain part of the shell material, but most of these also occur as molds. There is no evidence of recrystallization within the matrix, and owing to the exceedingly fine texture of the dolomite cement the fossil molds are in some cases excellently preserved. Relative to the preservation of the Whitehorse Bryozoa Moore finds that

"the preservation of the fossils is far from perfect. The surface of the zoarium is fairly well shown by four or five examples, but some of these are molds. Internal structure is well preserved in the material from some localities, although it is difficult to prepare thin sections because, owing to absence of filling of the zooecial tubes,

the fragile walls break very easily. Impregnation of a specimen with bakelite or canada balsam is a great help in making sections of such fossils, and this method was employed in order to secure satisfactory sections. The interior of some colonies contains no trace of the zooecial structure or only fragmentary portions of it; the space may be occupied by crystalline calcite or it may be a cavity. The molds of numerous zoaria show well enough the dimensions and form of the colonies but only in very poor manner reveal the terminal portions of the zooecial tubes, showing more or less definitely the outline and distribution of these tubes but nothing of the mesopores or acanthopores. Cores of bryozoan branches occur loosely filling the cavities of zoarial molds; these cores retain internal structures in varying degree of preservation."

ENVIRONMENT OF THE FAUNA

The paleoecologist has few materials indeed from which to reconstruct past environments. Commonly the records consist only of lithologic and stratigraphic evidence and the data supplied by the attitude and character of the fossils themselves. Admittedly the environments indicated by these inadequate data are not necessarily the life environments, because shells can be, and frequently are, transported by currents before being entombed and fossilized.

In some instances there are unusual or otherwise striking features of fossil faunas that invite speculation on the possible conditions of burial. This is true of the Whitehorse fauna. The Whitehorse fossils are practically confined to linear, cross-bedded, sandy and dolomitic "shoestring sand" lenses. As Bass (1938; 1939) has shown, these deposits have many of the characteristics of migratory offshore bars or barrier beaches. The strata that surround the bar deposits are generally much finer in texture, relatively soft, and barren of fossils.

Much gypsum, anhydrite, and some salt occurs distributed through the Whitehorse formation but never in the fossiliferous bar deposits. The assumption of an arid or semiarid climate during Whitehorse time seems justified and accords with the general concept of the physical conditions prevalent in the Mid-continent region during the deposition of the red beds.

In an attempt to explain the lack of fossils in beds surrounding the abundantly fossiliferous lenses, and the relative concentration of dolomite in the lenses, the following hypothesis is offered.

The lagunal environment behind the offshore bars of a hypersaline sea might well be more habitable to invertebrates than the water on the seaward side of the barriers. Streams draining the arid lands bordering the relic sea, although few in number, would effectively reduce the salinity of the water along the coast bordering the stream mouths. Lagunal areas behind offshore bars near the streams might well become a haven for such relics of a normal marine fauna that could exist under the rather difficult conditions of environment.

During the normal evolution of barrier bars wave erosion on the seaward face and deposition on the lagunal face tends to drive the bars inland, thus destroying the lagoons. Shells of invertebrates inhabiting the lagoons would become incorporated in the marching sands, whereas the sea bottom in front of the bars would be barren of shells.

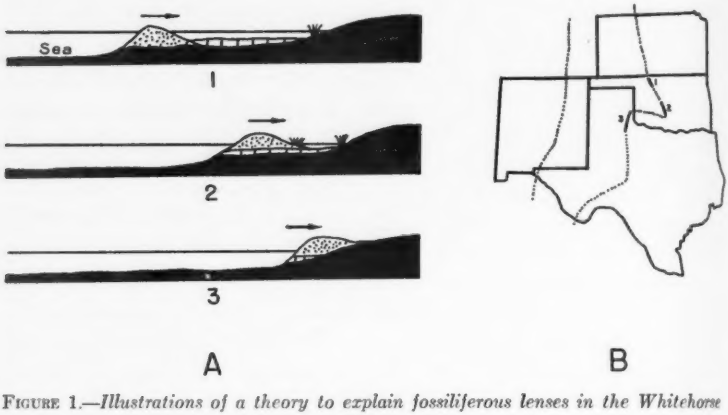

FIGURE 1.—*Illustrations of a theory to explain fossiliferous lenses in the Whitehorse sandstone*

If offshore bars were developed by waves and currents along coast of a shallow sea having abnormally high salinity, the water of lagoons behind the bars (A, 1) might be sufficiently freshened near stream mouths to become local havens for marine invertebrates. Dolomite marl (or perhaps originally limestone marl) deposited in the lagoons would ultimately be overridden by the landward migrating sand bars (A, 2). Shoreward advance of the bars would cause incorporation of calcareous mud and shells of invertebrates in the sand of the bars. Ultimately (A, 3) the lagoon might be destroyed by advancing sand. Basal beds of the resultant deposit would contain dolomite layers with complete shells, whereas the cross-bedded sands above would contain numerous but reworked and separated shells. Surrounding strata might generally be barren of fossils.

In Figure B is indicated the location of the three main fossiliferous bar deposits of the Whitehorse and the hypothetical limits of the sea in which the invertebrates lived: 1, Whitehorse Springs lens; 2, Verden lens; 3, Dozier lens.

Under favorable circumstances dolomite (perhaps limestone, originally) might be deposited in the lagoons more rapidly than in the turbulent waters along the shore of the open sea. If so, the incorporation of the dolomite lagunal deposits in the marching sand would make the bar deposits highly dolomitic as compared with the bottom sediments of the open sea. In some instances invertebrate shells would be buried in the limy mud of the lagoons, and the marching sands of the barrier ultimately would come to lie directly on such deposits, accounting for the nearly pure dolomite in the basal beds of the fossiliferous lenses. In several places fragile ramose Bryozoa were observed in the basal

beds of the lenses, some apparently in position of growth. Pelecypods with both valves intact are common in these basal dolomites. It is evident that such specimens could not have been transported intact but simply were buried by the advancing sand.

Although it is highly probable that the Whitehorse fauna lived in an unusual environment, there is nothing to indicate that the environment was that of fresh water, or even brackish water. Among the common genera represented the brachiopods *Dielasma* and *Composita,* particularly the former, suggest a marine fauna; *Schizodus, Pleurophorus, Edmondia, Allorisma, Parallelodon, Conocardium, Pernopecten,* and *Pseudamusium?* among the pelecypods certainly indicate a typical marine assemblage. The relatively abundant Bryozoa in the fauna suggests a salinity comparable with that of normal marine waters, for nonmarine Bryozoa are scarcely known in the fossil record. Likewise the gastropod genera represented are found elsewhere only in marine assemblages.

COMPOSITION OF THE FAUNA

The Whitehorse fauna is predominantly molluscan, 26 out of a total of 32 forms being pelecypods and gastropods. Pelecypods dominate the fauna in both variety and numbers. Two pelecypod species, *Dozierella gouldii* (Beede) and *Pleurophorus albequus* Beede, make up more than three-quarters of all specimens found. There are 14 kinds of pelecypods and 12 gastropod species.

Calcareous worm tubes belonging to *Spirorbis* sp. are fairly common, as are specimens of the one bryozoan species *Lioclema dozierense* Moore, n. sp. Brachiopods are represented by four species, none of which is abundant. Most of the species appear to be peculiar to the Whitehorse fauna, as they are as yet unknown elsewhere; they thus lend a distinctive facies to the fauna. Six new genera are described. Of these, two are thus far unknown elsewhere. Most of the original generic assignments of the Whitehorse species were incorrect and are now revised. Although seven new species are described, the total number of valid species has not been increased, because ten previously described forms are now placed in synonymies.

The pelecypod assemblage is a distinctive one, dominated by the new pterioid genus *Dozierella* and two forms of *Pleurophorus.* The species of *Conocardium* is of interest because it is possibly the youngest known species of that genus. Worthy of note is a small *Pseudamusium* ? sp., probably the only authentic record of a true pectinid in the Paleozoic, notwithstanding dozens of citations to the contrary.

The gastropod assemblage appears to be no less characteristic of the Whitehorse fauna than the pelecypods. Specimens of a *Murchisonia*

TABLE 1.—*Distribution of Whitehorse species*

	Localities										
	1	2	3	4	5	6	7	8	9	10	11
Edmondia rotunda Beede					x	x	x	x	x		
Dozierella gouldii (Beede)	x	x	x	x	x	x	x	x	x	x	x
Conocardium oklahomense Beede	x										
Myalina sp.	x						x				
Parallelodon sp.						x					
Gryphellina sellardsi (Beede)	x			x	x	x	x	x	x		
Schizodus oklahomensis Beede	x			x	x	x	x	x	x		
Aviculopecten vanvleeti Beede	x			x	x	x	x	x	x		
Pernopecten symmetricus Newell, n. sp.							x		x		
Pseudamusium? sp.							x				
Allorisma? *albequus* Beede				x	x	x	x	x	x		
Allorisma rothi Newell, n. sp.							x		x		
Pleurophorus albequus	x	x	x	x	x	x	x	x	x	x	x
Pleurophorus albequus longus Beede	x			x	x	x	x	x	x		
Spirorbis sp.	x			x	x	x	x	x	x		
Lepetopsis? haworthi (Beede)						x		x			
Bellerophon sp.								x			
Baylea capertoni (Beede)	x			x		x	x	x	x		
Worthenia beedei Knight, n. sp.									x		
Murchisonia gouldii Beede				x		x	x	x	x		
Taosia dozierensis (Beede)						x	x		x		
Cyclites depressus (Beede)	x										
Naticopsis transversus (Beede)	x			x		x	x	x	x		
Girtyspira? alvaensis (Beede)	x										
Streptacis permiana (Beede)						x	x	x			
Cyclobathmus haworthi (Beede)	x						x	x			
Plagioglypta girtyi Knight, n. sp.							x	x			
Dielasma schucherti Beede	x						x				
Pseudodielasma perpleza Brill, n. sp.	x						x		x		
Composita mexicana (Hall)	x						x		x		
Composita subcircularis Brill, n. sp.	x								x		
Lioclema dozierense Moore, n. sp.	x	x			x		x	x	x	x	

are more abundant than other gastropods. Perhaps most surprising for a late Paleozoic fauna is the peculiar brachiopod assemblage. Three genera are represented—*Dielasma*, *Pseudodielasma*, and *Composita*. Strophomenoid brachiopods are completely absent from the Whitehorse fauna, an anomalous situation when Permian faunas the world over are

considered. Productids particularly are characteristic of most late Paleozoic marine faunas but are absent from the Whitehorse fauna.

Significant light is shed on this problem by unpublished information discovered by the late Dr. George H. Girty and brought to our attention by Dr. P. B. King.

"The Carlsbad limestone, or back-reef facies, is barren of life over most of its extent, but for some miles back of the reef zone it contains fairly abundant fossils. Most of these are poorly preserved because of dolomitization, or difficult to collect on account of the hardness of the rock, but Mr. Fountain has succeeded in obtaining a rather large amount of material.

"Close to the reef, the most abundant remains in the Carlsbad limestone are fusulinids and pisolites. The fusulinids, like those in the upper Delaware Mountain and Capitan formations, belong to the zone of *Polydiexodina*. . . . The pisolites may be of algal origin. With them are other remains that are certainly algae. . . . In contrast to the great abundance of sponges in the Capitan, those in the Carlsbad are reduced to a single species.

"The remainder of the fauna, consisting largely of brachiopods, pelecypods, and gastropods, is very different from that in the Capitan and upper Delaware Mountain formations a few miles away, although they are proved by field work to be of the same age. Brachiopods are greatly diminished in numbers, and there is an astonishing absence of several great groups that have characterized all the Permian rocks so far described. According to Girty, 'Against 50 species in the Capitan, the Carlsbad contains 14, and what is more remarkable, the groups of Productidae and Spiriferae are unrepresented. The forms chiefly present belong to the Orthotetinae and Terebratulidae.' Besides this, there is also an absence of such familiar genera as *Chonetes, Camerophoria, Hustedia, Aulosteges,* and *Leptodus*. *Prorichthofenia,* however, is abundant, and the Orthotetinae include a large, wrinkled *Plicatoderbya*.

"By contrast, the gastropods of the Carlsbad are much more numerous than in the Capitan, and in fact dominate the fauna. They include various bellerophontids, *Pleurotomaria, Naticopsis,* and *Trachydomia*. Pelecypods are less abundant than gastropods, and are not as abundant as in the Capitan. Many Capitan genera are present, but not all the species are the same."

This new information on the Carlsbad fauna lends support to the suggestion that the Whitehorse fauna may be a facies modification of the Capitan fauna.

RELATIONS AND AGE OF FAUNA

Stratigraphic relations.—Permian strata in much of north-central Texas are concealed by Mesozoic and Cenozoic rocks, so that it is not possible to trace outcrops from the Mid-continent region into the abundantly fossiliferous Permian sections of the Guadalupe and Glass Mountains in Trans-Pecos Texas. However, deep borings have contributed much information in recent years. The Whitehorse section is readily recognizable in the subsurface over much of northern and central Texas (Adams, 1935). Long experience in the region has convinced many geologists such as Lang (1937, p. 857, 879), De Ford (1938, p. 37), and Adams (1935, p. 1015) that the Whitehorse section grades laterally toward the southwest into the Dog Canyon (Word equivalent) and Capitan formations of the Guadalupe Mountains. These authorities regard the Carlsbad limestone as a facies of the Capitan formation. It has been the opinion of others, principally John W. Skinner and Robert Roth

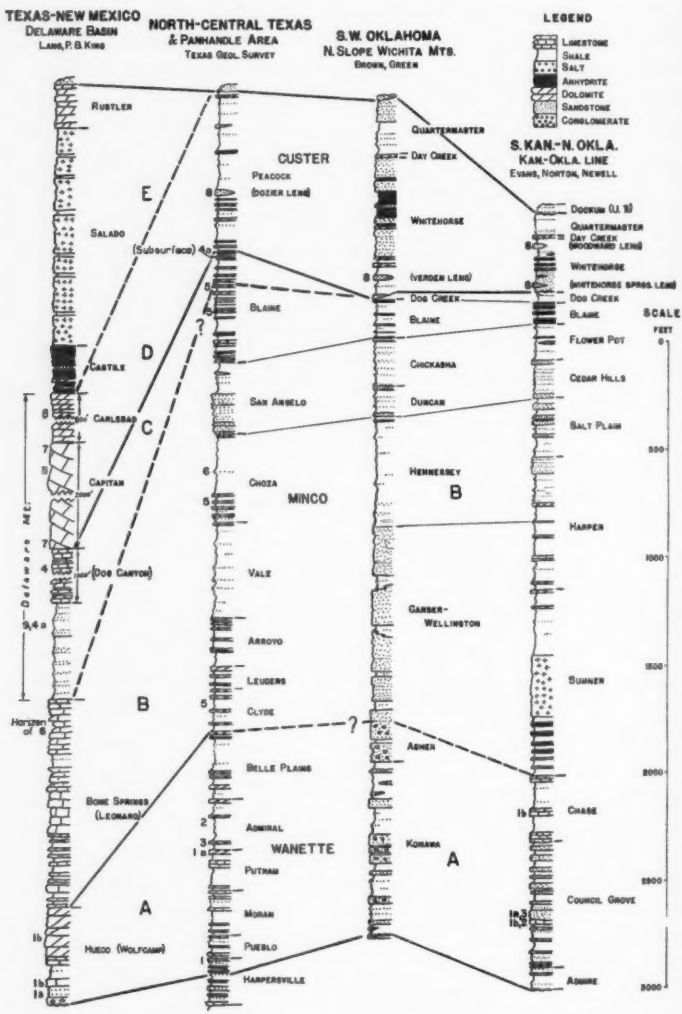

FIGURE 2.—*Tentative correlation of Permian sections of Kansas, Oklahoma, and Texas*

Heavy correlation lines indicate major stratigraphic divisions; broken lines represent less secure correlations. A, zone of *Pseudoschwagerina* and *Properrinites;* B, zone of primitive *Parafusulina* and *Perrinites;* C, zone of advanced *Parafusulina* and *Waagenoceras;* D, zone of *Polydiexodina;* E, highest unfossiliferous evaporites, largely confined, apparently, to southeast New Mexico and adjacent West Texas. Small numbers on left of each column indicate occurrences of significant fossils: 1, *Schwagerina* s.s.; 1a, *Schwagerina emaciata;* 1b, *Schwagerina* and *Pseudoschwagerina;* 2, *Properrinites;* 3, *Artinskia;* 4, *Parafusulina;* 4a, *Parafusulina rothi* and *P. maleyi referta;* 5, *Perrinites;* 6, *Schubertella melonica* (found near top of type Leonard); 7, *Polydiexodina;* 8, *Dozierella* fauna of lower "Custer"; 9, *Waagenoceras.*

(personal communication), that the lower part of the Whitehorse sandstone may rest unconformably on the *Polydiexodina*-bearing "Carlsbad" and the Capitan limestone. According to this interpretation the entire "Custer" might be younger than the Capitan.

TABLE 2.—*Sequence and tentative correlation of Permian rocks*

West Texas		Northwest Texas	Oklahoma-Kansas
Triassic		Triassic	Triassic
Dewey Lake Rustler Salado Castile		Absent? (Upper "Custer"?)	Absent?
Carlsbad Capitan Dog Canyon	Delaware Mt.	"Custer" *Parafusulina* beds (subsurface)	"Custer" {Quartermaster, Day Creek, Whitehorse} Absent?
		?	
Bone Spring		Blaine San Angelo Clear Fork Wichita	Dog Creek Blaine Chickasha Duncan Hennessey Garber
Hueco		Upper Cisco	Big Blue

It thus is evident that the surface and subsurface data may be interpreted in two ways. According to one interpretation there is a separate limestone unit above the Capitan—the Carlsbad—which is relatively unfossiliferous and which grades outward from the Delaware Basin into evaporites of Whitehorse age and basinward into evaporites of the Castile formation. The view adhered to by the majority of workers in the region, however, is that the evaporites of Whitehorse age pass southward into unfossiliferous limestones of the Carlsbad; these grade into the *Polydiexodina*-bearing facies of the Carlsbad and thence into the reef limestones of the Capitan, which in turn interfinger with the Delaware Mountain formation of the Delaware Basin. According to the first view the Whitehorse fauna is younger than the late Permian Capitan fauna, which is generally regarded as the youngest Permian marine fauna in North America. According to the second view the Whitehorse fauna is contemporaneous with the Capitan fauna and is different because of markedly different environment. The adherents of this interpretation regard the Castile, Salado, Rustler, and Dewey Lake formations of the Delaware Basin area as being younger than the Whitehorse of the Texas Panhandle and Oklahoma areas. According to both views the Carlsbad

limestone is equivalent to the Whitehorse, and fossils common to the Carlsbad and Whitehorse beds are in harmony with such a correlation.

Neither fusulines nor ammonoids[1] have been found associated with the typically molluscan fauna of the Whitehorse sandstone. Represen-

FIGURE 3.—*Diagrammatic sections across the northern rim of the Delaware Basin in southeastern New Mexico*

Modified from Lang (1937) and representing two interpretations of the stratigraphic relations. In *A* the "Custer" group rests unconformably on Capitan limestone, passing completely over the Capitan reefs, and is equivalent, in part, to the Carlsbad limestone, Castile, and perhaps later evaporites. In *B* the "Custer" group is a lateral equivalent of the Delaware Mountain formation, the latter, however, being confined to the Delaware Basin and overlapped in the region of typical development of the "Custer", northwestern Texas and Oklahoma.

tatives of either of these two groups of fossils might aid greatly in a precise dating, but apparently they did not penetrate into the red beds environment during Whitehorse time. Fusulines and ammonoids are found, however, in rocks underneath those which bear the Whitehorse fauna.

Ammonoids were reported in central Texas 50 years ago by Cummins (1890, p. 408) from a thin dolomite bed now believed to be the Aspermont bed (Roth, 1937, p. 462-464) in the upper part of the Blaine formation. This horizon lies 175 feet below the unconformity at the base of the Whitehorse and about 425 feet below the Dozier sandstone from which the Whitehorse fossils in this part of Texas are obtained.[2] The pertinent species found in the Aspermont dolomite is *Perrinites hilli* (Smith). The genus *Perrinites* has long been regarded as diagnostic of

[1] The citation of ammonoids in the lower Peacock formation (Whitehorse) of north-central Texas by Plummer and Scott (1937, p. 19, 398) is now known to refer to specimens from the Aspermont dolomite of the Blaine formation at the falls of Salt Croton creek, Stonewall County, Texas.

[2] Since this was written a well-preserved and characteristic *Aviculopecten vanvleeti* Beede from the Childress dolomite in the basal part of the Whitehorse formation has been received from Roth. The specimen comes from the east side of section 484, W. and N.W.R.R. Survey, Childress County, Texas, about 10 feet above the base of the Whitehorse formation. This species is one of the characteristic Dozier forms although it was found well below the horizon of the Dozier sandstone.

Leonard age, and is replaced in higher horizons of the Word by *Waagenoceras*. Plummer and Scott (1937, p. 304, 398), however, regard *Perrinites hilli* as much more advanced and therefore presumably younger than the west Texas representatives of *Perrinites* found in the Leonard formation.

A restudy of large suites of *Perrinites hilli* from the Aspermont dolomite and the Leonard *Perrinites vidriensis* Böse by Miller and Furnish (personal communication) has led these authorities to regard the two forms as conspecific, and they therefore regard the Aspermont horizon as late Leonard.

If the ammonoid *Perrinites hilli*, found in the Aspermont bed of the Blaine, indicates a late Leonard age for that horizon, then the overlying Whitehorse sandstone is probably younger than Leonard.

Fusulinids are not found in undoubted beds of the Whitehorse sandstone but are abundant near the base of the Whitehorse, in the upper beds of the "Big Lime" of the subsurface in central Texas. The exact position of the lower boundary of the Whitehorse relative to the Big Lime is under debate.

Roth (personal communication) writes:

> "In the Yates pool, the basal Custer rests upon a very porous limestone which contains poorly preserved small *Parafusulina*. . . . In the McElroy pool *Parafusulina* underlies the Custer equivalents. At Big Lake, the lower Custer rests upon a very porous oölitic limestone containing *Parafusulina lineata* and *P. rothi* which are very high in the Delaware section."

Skinner recognizes *Parafusulina maleyi* var. *referta* and *P. rothi* from the zone (Texon pay) below the Whitehorse beds at the Big Lake oil field, at the top of the Big Lime in Reagan County, Texas. Skinner believes (personal communication) that these fusulinid beds occur just below the Whitehorse beds in rocks that are post-Blaine, pre-Whitehorse in age.

Adams (personal communication) would place the base of the Whitehorse at about 240 feet below the Texon pay with its *Parafusulina rothi* fauna, so that the fusulines are assigned by him to the lower part of the Custer.

These fusulines indicate an equivalence with the middle Delaware Mountain sandstone of the Guadalupe Mountains and the upper part of the Word formation of the Glass Mountains. (*See* Dunbar and Skinner, 1938). Accordingly, if the fusulines of the Texon pay zone occur in the lower Custer the lower 200 feet or so of the Custer can be no older than late Word. According to this correlation much of the Custer, possibly including the beds with the typical Whitehorse molluscan fauna, would probably correlate with the Capitan horizons farther to the west. If on the other hand the fusulines at Big Lake occur entirely

below the base of the Whitehorse it would seem likely that the lower Whitehorse is at least as young as the Capitan.

Age of the fauna.—The generic assemblage of the Whitehorse fauna clearly indicates a Paleozoic age. Most of the genera are confined to late Paleozoic rocks in other regions. There are a few genera, however,

TABLE 3.—*Comparable Whitehorse and Guadalupian species*

Whitehorse species		Guadalupian species
Myalina sp.	compare	*Myalina squamosa?* Girty, Capitan
Allorisma? albequus Beede	compare	*Edmondia bellula* Girty, Capitan
Cyclites depressus (Beede)	equals	*Pleurotomaria multilineata* Girty, Delaware
Murchisonia gouldii Beede	equals	*Murchisonia gouldii* Beede, Capitan
Baylea capertoni (Beede)	compare	*Pleurotomaria texana* Girty, Capitan
Pseudodielasma perplexa Brill	compare	*Pseudodielasma? minor* (King), Word
Composita mexicana (Hall)	equals	*Composita mexicana* (Hall), Leonard
Lioclema dozierense Moore	compare	*Lioclema shumardi* Girty, Capitan

that have been reported from Triassic rocks. In several instances these citations are made under circumstances that invite doubt as to their authenticity. It is generally conceded that the following genera are restricted to late Paleozoic rocks: *Baylea, Taosia, Cyclites, Streptacis, Cyclobathmus, Edmondia, Conocardium, Parallelodon, Pernopecten, Allorisma, Dielasma, Composita,* and *Lioclema.* The following genera, represented in the Whitehorse fauna, are commonly cited from the Paleozoic but may be represented in the Triassic: *Bellerophon, Worthenia, Murchisonia, Naticopsis, Plagioglypta, Myalina, Schizodus, Aviculopecten,* and *Pleurophorus.* It is the writers' opinion, however, that the Triassic species referred to *Myalina, Schizodus, Aviculopecten,* and *Pleurophorus* are not congeneric with any of the Whitehorse forms and should be referred to other genera. *Lepetopsis* and *Girtyspira* are Paleozoic genera to which Whitehorse species are doubtfully referred. One Whitehorse form is doubtfully classed as *Pseudamusium,* a genus which Newell (1938) recently thought was exclusively post-Paleozoic.

The specific assemblage is a novel one, and most of the forms are thus far unknown outside of the Whitehorse formation. A few species however can profitably be compared with Guadalupian forms from the near-by western Texas area. Resemblances with other American faunas are not sufficiently close to invite comparison. Table 3 indicates the only close similarities now known to exist between the Whitehorse fauna and Permian faunas of western Texas.

There are only three specific identities recognized in the Whitehorse and Guadalupian faunas, and eight forms in both faunas that can fruitfully be compared. For the Guadalupian fauna of about 400 species

and the Whitehorse fauna of 32 species the evidence for contemporaneity is scant indeed. Of the various Guadalupian horizons the Capitan and equivalents show the greatest similarity to the Whitehorse, but the evidence for equivalency is scarcely more than suggestive. The faunal evi-

TABLE 4.—*Similar species in Whitehorse and Russian faunas*

Whitehorse fauna		Russian faunas
Dozierella gouldii (Beede)	compare	*Cyrtodontarca bakewellioides* Jakovlev, Bakmuth
Dozierella gouldii (Beede)	compare	*Pseudobakewellia krasnowidowiensis* Netschaev, Kazanian
Pleurophorus albequus Beede	compare	*Pleurophorina simplex* (Keyserling), Kazanian
Allorisma rothi Newell	compare	*Sanguinolites lacvigatus* Licharew, Kazanian
Conocardium oklahomense Beede	compare	*Conocardium tschernyschewi* Licharew, Kazanian
Cyclobathmus haworthi (Beede)	compare	*Tretospira divesouralica* Jakovlev, Bakmuth
Murchisonia gouldii Beede	compare	*Murchisonia* spp. Jakovlev, Bakmuth
Baylea capertoni (Beede)	compare	*Wortheniopsis kyschertinaeformis* Jakovlev, Bakmuth

dence alone suggests two possibilities. The Whitehorse formation may be contemporaneous with the Capitan, as is indicated by stratigraphic evidence discussed above, in which case the vast differences between the faunas might have been caused by ecological differences. An alternate possibility is that the Whitehorse fauna is considerably younger than that of the Capitan formation as suggested by Roth, yet pre-Triassic in age. Thus far determinable invertebrates have not been discovered in the evaporite series above the Capitan horizons in the Delaware Basin area. It is possible that if such faunas are ultimately found they will more closely resemble the Whitehorse fauna than does the Capitan fauna.

Outside of North America the only faunas that can profitably be compared with the Whitehorse fauna are the late Permian Kazanian faunas of the Russian platform and the fauna from the Bakmuth dolomites in the Donetz Basin. Even here the differences are far more marked than resemblances so that synchroneity is not necessarily implied. Table 4 summarizes the more significant similarities.

Two Whitehorse species are closely similar to forms from the Permian of the Salt Range in India. *Schizodus oklahomensis* Beede is strikingly like *Myophoria praecox* Waagen from the uppermost beds of the *Productus* Limestone, and *Dielasma schucherti* Beede is very like *Dielasma biplex* from the middle *Productus* Limestone.

From the foregoing discussion it is seen that the Whitehorse fauna is clearly Permian, but the unique facies of the fauna makes difficult a precise assignment to one of the standard subdivisions of the Permian. The closest relationships within the Permian system are found in the

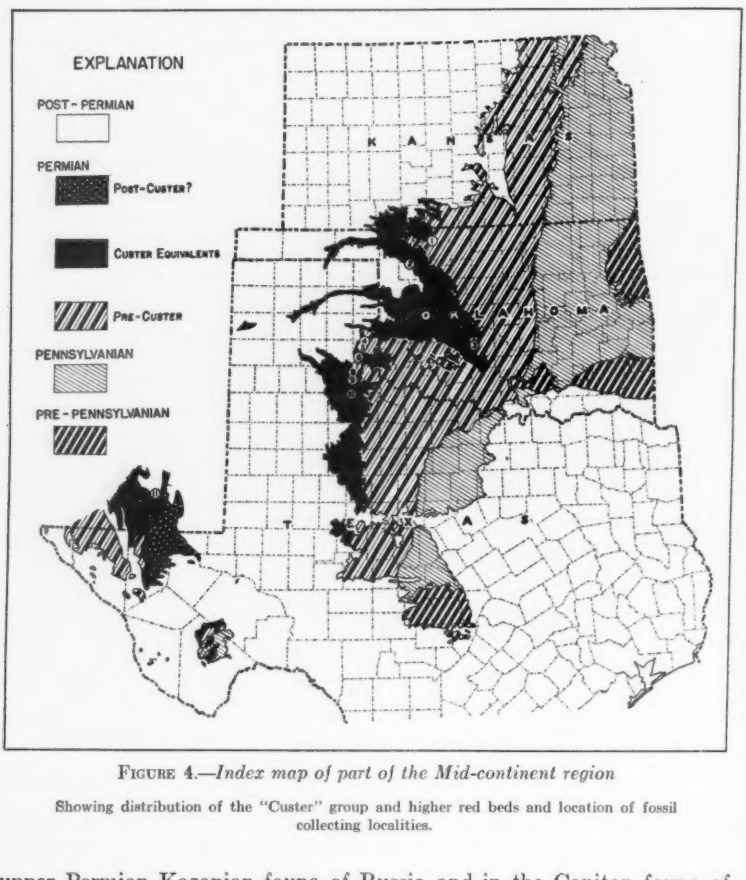

FIGURE 4.—*Index map of part of the Mid-continent region*

Showing distribution of the "Custer" group and higher red beds and location of fossil collecting localities.

upper Permian Kazanian fauna of Russia and in the Capitan fauna of Texas, yet these resemblances are so vague as to be merely suggestive.

LOCALITIES

(1) Sixteen miles due west of Alva, Woods County, Oklahoma, a quarter of a mile due north of highway; top of escarpment just west of "Whitehorse spring", located about 2 miles southeast of Whitehorse post office. The fossils occur in

dolomitic, cross-bedded red sandstone a few feet above the base of the Whitehorse formation. The dolomitic lens is referred to in this paper as the "Whitehorse Springs lens". The fauna consists of numbers of *Dielasma schucherti,* many pelecypods and gastropods of a few species, and only a few fragmentary Bryozoa.

(2) Four miles due east of Woodward, Oklahoma, in sandstone quarries on the south bank of North Canadian River. Fossils are chiefly Bryozoa and pelecypods of a few species. Some of the Bryozoa occur near the base of the sandstone and are clearly in position of growth, forming little bioherms up to a foot thick. Unfortunately these Bryozoa—ramose types—do not exhibit any internal structure. This dolomitic sandstone lens is designated in this paper the "Woodward lens". This horizon is considerably higher stratigraphically than the Whitehorse Springs lens.

(3) Escarpment of the Verden sandstone lens at the SE ¼ SE ¼ sec. 4, T. 6 N., R. 8 W., near Chickasha, Grady County, Oklahoma. The fossils, chiefly *Dozierella gouldii,* occur in cross-bedded, dolomitic red sandstone. Collection by N. W. Bass.

(4) Three miles southwest of Shamrock, Collingsworth County, Texas, in the Dozier lens capping Rocking Chair Mounds. The fossils, chiefly pelecypods and gastropods, occur in red, cross-bedded, highly dolomitic sandstone.

(5) Two miles north and 2½ miles east of Dozier, about 5 miles southwest of Shamrock, Collingsworth County, Texas. The fossils occur in the Dozier sandstone lens which caps Antelope Buttes. Collections made at the northernmost butte near center of section line. Lenses of nearly pure dolomite filled with well-preserved molds occur at the base of the sandstone. Some of the Bryozoa found here apparently occur in the original growth position.

(6) Two miles east and 2 miles south of Dozier, Collingsworth County, Texas, from the Dozier sandstone at the summit of Dozier Mounds. Another collection from this vicinity was made by Robert Roth in section 28, Block 16 of the H. G. and N. Survey (Roth's 376-C).

(7) A series of four collections made by Robert Roth from the dolomite beds at the base of the Dozier lens at closely adjoining outcrops in the southwestern part of Collingsworth County, Texas. The specimens are well-preserved molds exhibiting almost no signs of abrasion. Many of the bivalves have the two valves in apposition. Pelecypods predominate, but gastropods are numerous, brachiopods are common, and the collections contain a few poorly preserved Bryozoa: (a) Section 43, Block 19, H. G. and N. Survey (Roth's 376-A); (b) east side of section 44, Block 19 (Roth's 378-B); (c) southwest corner of section 78, Block 19 (Roth's 378); (d) south side of section 78, Block 19 (Roth's 378-A).

(8) Two collections from the base of the Dozier lens south of Memphis, Hall County, Texas: (a) 6 miles due south of Memphis, summit of Hogback Butte. Brachiopods and pelecypods are abundant, with a few gastropods and Bryozoa. Specimens in the dolomite at the base of the Dozier lens are well preserved as molds and show almost no sign of abrasion. The sandstone layers a few feet above the base contain separated, but generally unbroken valves of pelecypods. (b) Top of first high hill on east side of Estelline-Memphis road, section 7, Block 18, H. G. and N. Survey (Roth's 361-H).

(9) Three miles due west of Estelline, Hall County, Texas. Collections from the dolomite beds at the base of the Dozier lens on the summit of Naco Butte (Mt. Nebo) on the north side of the highway. Includes a collection from this locality by Roth (Roth's 361-C). Mollusks predominate and are well preserved. A number of small bioherms of ramose Bryozoa appear to lie in the original position of growth in the dolomite.

(10) West end of bridge over North Pease River on highway just west of Northfield, Motley County, Texas. Pelecypods are common, chiefly *Dozierella gouldii;* Bryozoa are common but fragmentary. A few of the zoaria exhibit well-preserved internal structures. According to Roth this horizon is also the Dozier sandstone.

(11) Six miles southwest of Lakewood, Eddy County, New Mexico, and about 15 miles north of Carlsbad, basal beds of the Azotea tongue of the Carlsbad limestone

about 10 feet below crest of Seven Rivers escarpment and a little to the west of the east end of the ridge. Locality about a quarter of a mile west of the Carlsbad-Roswell highway. Specimens of *Dozierella gouldii* and *Pleurophorus albequus* were recognized in the dense, massive dolomite. This is the locality discovered and described by Beede.

CONCLUSIONS

The location of the Paleozoic-Mesozoic boundary in the red beds of the Mid-continent region has been debated, and recently the controversy has centered on the age of the "Custer" group, as originally defined by Robert Roth. The Whitehorse sandstone at the base of the Custer is underlain unconformably by rocks containing faunas indicating either a Leonard or Word age. The Custer group is overlain unconformably by the Dockum beds containing a fauna of terrestrial vertebrates of undoubted late Triassic age. A fauna of marine invertebrates occurs in deposits of cross-bedded sandstone and dolomite in the Whitehorse sandstone. Beede studied this fauna and assigned it to the Permian, an assignment which has generally been accepted. Some geologists, however, have looked upon Beede's faunal evidence as inconclusive and have referred the entire Custer to the Triassic.

If the Whitehorse beds could be traced at the surface continuously from northwestern Texas into the near-by Guadalupe Mountains of southeastern New Mexico and Trans-Pecos Texas it would be easy to date the Whitehorse sandstone relative to the Permian of the Guadalupian section. The red beds of the Whitehorse sandstone and associated strata are covered, however, by late Triassic and Tertiary deposits in much of northwestern Texas, so that continuity in the direction of the west Texas outcrops can be studied only from the records of deep borings.

Texas geologists are not agreed on the subsurface correlations of the Whitehorse beds with equivalents in New Mexico and western Texas. To most workers, however, voluminous subsurface data indicate that the Whitehorse grades directly into the Delaware Mountain and Capitan limestone of late Permian age. Other geologists conclude that the Whitehorse completely overlies and is entirely younger than the Capitan formation. According to this view the Whitehorse sandstone might be early or medial Triassic.

The present investigation is primarily concerned with a restudy of the invertebrate fauna of the Whitehorse formation. The results of this investigation clearly indicate a late Permian age for the fauna. Whitehorse species occur in the Azotea tongue of the Carlsbad limestone, so that correlation of the Whitehorse and Carlsbad units seems reasonable. However, geologists familiar with the Guadalupe Mountains are not all agreed as to whether the Carlsbad limestone is equivalent to or younger than the Capitan limestone.

The lithologic facies of the red beds Whitehorse sandstone with its gypsum and salt beds is quite unlike that of the more nearly normal marine sequence of the Guadalupe Mountains; therefore it is not surprising that the faunas of the two facies are dissimilar. The fact that the faunas are so profoundly different, however, is not necessarily explainable on ecological grounds alone. The Whitehorse fauna is not simply an impoverished and modified Guadalupian fauna. Presumably the Whitehorse fauna entered the Mid-continent from the southwest, as did other late Paleozoic faunas. Yet, some of the commonest Whitehorse species are as yet unknown in the prolific faunas of the Guadalupe or Marathon areas.

Strophomenoid brachiopods, including productids, are completely absent from the Whitehorse fauna. The relative abundance of terebratuloid brachiopods and absence of strophomenoids gives the fauna a pronounced, though superficial, Mesozoic aspect. The generic make-up of the fauna is clearly late Paleozoic, and no typically Triassic forms are present.

Although the Whitehorse fauna is unique among Permian faunas of the world there are a few vague resemblances to the Kazanian (late Permian) of the Russian platform and to the Bakmuth dolomites of the Donetz basin. The resemblances are not sufficiently close, however, to justify more than approximate correlations. One pelecypod bears marked resemblance to a distinctive species from the upper *Productus* Limestone (*Cyclolobus* beds) of northern India. One brachiopod is very like a species from the middle *Productus* Limestone.

Faunal and stratigraphic evidence indicates at least partial equivalence with the Carlsbad limestone of southeastern New Mexico. The age of the Carlsbad limestone is controversial; preponderance of opinion, however, indicates a Capitan age. The faunal evidence presented here favors correlation of the Whitehorse sandstone with part of the Delaware Mountain and Capitan formations of western Texas but is insufficient to be wholly conclusive.

PELECYPODS OF THE WHITEHORSE SANDSTONE

Family GRAMMYSIIDAE

Genus *Edmondia* de Koninck

Edmondia rotunda Beede

(Plate 2, figures 18-21)

Edmondia rotunda BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 150, pl. 7, figs. 3, 3b.
Edmondia cumminsi BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 151, pl. 7, figs. 4, 4a.

DESCRIPTION: Shell very small for the genus, averaging about 6 mm. in height, 7 mm. in length, and 2 or 3 mm. in thickness in full-sized individuals; form elongate

oval to subcircular with highly convex to subhemispherical valves; beaks prosogyre, gibbous, located one-third of the shell length behind the front margin; surface ornamented by distinct and regularly spaced concentric fila or lirae separated by slightly broader, flat interspaces, about 6 in 1 mm. near the midventral margin in mature specimens; isomyarian, with adductors relatively large, the anterior one relatively deeply impressed; impressions located just under each extremity of the hinge plate; pallial line entire, located close to the shell margin; broad groove, apparently for ligament, located on hinge plate behind beaks.

Shell measurements in Edmondia rotunda

Specimen (valves)	Length (mm.)	Height (mm.)	Convexity (mm.)
1. Left, cast	7.5	7.5	4±
2. Right, cast	7±	6±	3±
3. Left, internal mold	6±	5.0	2±
4. Left, internal mold	6.5	5±	2.0
5. Left	7.0	6.0	2+
6. Left, external mold	6.5	5.0	2.0

Discussion: The similarity in form and ornamentation of most of the species of *Edmondia* makes differentiation within the genus difficult. Nevertheless *E. rotunda* is relatively distinctive in the small size of mature individuals and in the high convexity of the valves. The fine collections demonstrate that Beede's *Edmondia cumminsi* is conspecific with the present species and does not represent even a well-defined variety.

Apparently *Edmondia* invariably is found associated with "normal" marine assemblages in the Paleozoic. Diener (1923) and Kutassy (1931) do not cite examples of *Edmondia* in the Triassic, nor is any Triassic pelecypod known that is closely similar to *Edmondia*. The occurrence of the genus, therefore, in the Whitehorse horizons points to a Paleozoic age for these rocks.

The type specimens of *Edmondia rotunda* (type nos. 161-A, B) and *E. cumminsi* (no. 162) are preserved in the collections at the University of Kansas Geological Museum; they are poorly preserved internal molds. Undoubtedly the species could not be recognized from only the type specimens.

Occurrence: This species occurs rather sparsely in the more dolomitic phases of the Dozier sandstone in northwestern Texas. Specimens were collected at localities 5, 6, 7, 8, and 9.

Family Liopteriidae

Genus *Dozierella* Newell, n. g.

Bakewellia Beede, Oklahoma Geol. Survey, 1st Bienn. Rept., Advance Bull. (1902), p. 5.

Cyrtodontarca Beede, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 152.

Description: Unornamented, pterioid, anisomyarian shells having the arcid type of ligament with several chevron ligament grooves; valves moderately convex, the right one very slightly less convex; dentition distinctive, two lamellar posterior lateral teeth in the right and one in the left valve, and three or more cardinals in the left and four or more in the right valve; anterior two teeth in the right valve relatively large, the foremost elongate in a direction at right angles to the hinge axis and parallel to the inner margin of the hinge plate, whereas the second cardinal, although slightly curved downward at both extremities, is nevertheless essentially

parallel to the hinge axis; anterior cardinal of the left valve arcuate, elongated parallel to the inner margin of the hinge plate so that its posterior and dorsal portion is essentially parallel to the hinge axis and the anteroventral part trends at right angles to the hinge axis; distinct byssal notch or opening absent.

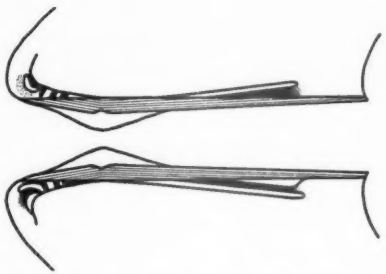

FIGURE 5.—*Diagrammatic representation of the new genus Dozierella*

Based on artificial casts of several specimens. Although dentition and ligament were similar to that of *Parallelodon*, the form of the shell is distinctly pterioid.

GENOTYPE SPECIES: *Bakewellia gouldii* Beede from the Whitehorse sandstone of Oklahoma and Texas, and the Azotea member of the Carlsbad limestone in New Mexico.

DISCUSSION: Much confusion surrounds the actual characters and interpretation of characters in Paleozoic pterioid genera like *Liopteria* Hall, *Cyrtodontarca* Jakovlev, *Bakewellia* King, *Pseudobakewellia* Noinsky, *Merismopteria* Etheridge, and similar forms. *Bakewellia*, with its *Perna*-like ligament, evidently belongs to quite a different family from the Liopteriidae. Significant features of the ligament area and dentition of *Pseudobakewellia* are unknown. However, *Pseudobakewellia* is supposed to have a smooth ligament area, unlike *Bakewellia* or any of the Liopteriidae. The genus *Merismopteria* from the Australian Permian, possibly a synonym of *Liopteria*, needs reinvestigation; its diagnostic features are lack of cardinal teeth and possession of a heavy buttress immediately in front of the anterior adductor impression.

Similar to *Dozierella* is *Cyrtodontarca* Jakovlev from the Bakmuth dolomites of the Donetz coal basin. These beds are said to contain *Pseudoschwagerina princeps* but are associated with other fossils that seem to indicate an age no older than Artinskian and probably are much younger than the American Wolfcamp-Big Blue horizons (B. K. Licharew, oral communication). Lee (1937) reports *P. princeps* from a horizon several thousand feet below the *Cyrtodontarca* beds in the Donetz basin.

Beede referred the present form to *Cyrtodontarca* because of general similarity. However, Jakovlev's (1903, p. 36-39) genus has an exceedingly complex arrangement of the cardinal teeth. A restudy of the type specimens of the genotype, together with adequate supplementary material, is strongly urged. The distinctive arrange-

ment of the cardinal teeth in *Dozierella* is not recognizable in the cardinals of *Cyrtodontarca*. Probably the two genera are very closely related.

Triassic pelecypods similar to *Dozierella* are not known.

Dozierella gouldii (Beede)

(Plate 1, figures 14-22)

Bakewellia gouldii Beede, Oklahoma Geol. Survey, 1st Bienn. Rept., Advance Bull. (1902) p. 5, pl. 1, figs. 2-2c.

Cyrtodontarca? gouldii Beede, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 152, pl. 6, figs. 1-1e.

Cyrtodontarca? multidentata Beede, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 153, pl. 5, figs. 4, 4a.

Cyrtodontarca? parallelidentata Beede, Kansas Univ. Sci. Bull., vol. 4 (1907) pl. 6, figs. 6-6c.

Description: Shell pterioid, noncostate, elongate, moderately convex, slightly inequivalve, the right valve less convex; small, length ranging from 10 to 20 mm., and height from 5 to 10 mm.; auricles short and only moderately well defined, the outer margins of the posterior auricle forming an angle ranging from 80 to about 140 degrees; beaks relatively acute, extending slightly above the hinge axis, located from about one-sixth to one-fifth of the hinge length back of the anterior margin; shell body markedly oblique, with the midumbonal bisectrix intersecting the cardinal margin anteriorly at an angle of approximately 45 degrees, gradually flattening out posteriorly so as to form a smaller angle with the hinge line; posterior portion of the shell projected behind the rear termination of the hinge by one-third of the shell length; broad sulci set the auricles off from the shell body and are about coextensive with the auricles; byssal (?) sinus broad and obscure, about equally developed in both valves and located slightly above the middle of the anteroventral margin of the shell; ligament area arcid, with at least four or five closely spaced chevron grooves in full-sized individuals, apex of chevrons being placed under the beaks; ligament area about one-tenth as broad as long; adductors anisomyarian, anterior one small, located just in front of beaks in a conspicuous muscle pit, that of right valve being more clearly defined and deeper; pedal retractors indicated by one conspicuous pit at the apex of the umbonal recess, that of right valve being the larger and deeper; posterior adductor impression oval, three or four times as broad as anterior impression, located directly below the posterior end of hinge; dentition in mature individuals: one lamellar posterior lateral and three (rarely more) cardinals in the left valve, two lamellar posterior laterals and four (rarely more) cardinals in the right valve; posterior cardinals lacking in juveniles, added only during late ontogeny; cardinal teeth oblique, directed backward, subparallel with axis of shell obliquity, except for anterior one in left valve, which is prominent, arcuate, and elongated parallel to and located slightly in front of inner margin of the hinge plate; anterior two cardinals of right valve elongate and arcuate, the front one occurring at and parallel to the inner edge of the hinge plate, whereas the second tooth is situated just below the hinge axis and subparallel to it, with extremities curved downward away from the hinge axis.

Discussion: The forms described by Beede under the names *D. multidentata* and *D. parallelidentata* are almost certainly conspecific with *Dozierella gouldii*. It is difficult to interpret the dentition of these shells without recourse to artificial casts, and because of the complexity and small size of the hinge teeth ordinary wax or clay "squeezes" do not give an accurate representation of the hinge characters. The species *D. parallelidentata*, as shown by the type specimens, is in no significant

way different from *D. gouldii*. The form *D. multidentata* was based on specimens having six cardinals in the left valve and five in the right one. Since the number of cardinal teeth appears to increase with growth by addition of new teeth at the posterior end of the series the variation in number appears to be simply an ontogenetic feature.

Shell measurements in Dozierella gouldii

Specimen (valves)	Length (mm.)	Height (mm.)	Hinge Length* (mm.)	Length Rear auricle (mm.)
1. Left, internal mold	20.0	10.0	10.0	8.5
2. Left, internal mold	10.5	5.5	6.5	5.5
3. Left, internal mold	13.0	7.0	7.5	6.3
4. Left, internal mold	15.0	9.0	9.0	7.0
5. Left, internal mold	19.0	10.0	12.0	10.0
6. Left, internal mold	....	9.0	12.0	10.0
7. Left, internal mold	12.5	7.0	8.0	6.5
8. Left, internal mold	12.0	7.0	8.3	7.0
9. Left, internal mold	13.0	6.0	8.5	7.0
10. Left, shell	12.0	8.0	9.0	7.0
11. Right, internal mold	13.0	8.0	11.0	9.2
12. Right, internal mold	14.0	7.0	9.5	8.5
13. Right, internal mold	....	....	8.0	6.5
14. Right, internal mold	10.0	5.0	8.0	6.2
15. Right, internal mold	13.0	6.5	8.5	7.5

* From tip of rear auricle to front of anterior auricle, a little more than the true hinge length.

Dozierella gouldii cannot be compared in detail with other similar species because the hinge characters are known in very few of the late Paleozoic pterioids. *Cyrtodontarca bakewellioides* Jakovlev from the higher beds in the Permian section of the Donetz basin strongly resembles the present species. However, *Cyrtodontarca* differs from *Dozierella* in important features, as discussed above. The type of *Pseudobakewellia—P. krasnowidowoensis* Netschaev—from the upper Permian Kazanian of the Russian platform is superficially like *Dozierella gouldii* but is supposed to have a hinge quite unlike the American species. It may be that further examination of the Russian forms will reveal greater similarity to *Dozierella* than seems to exist. There is no American species with which this one is likely to be confused.

The types of *Dozierella gouldii* (Beede) were long ago destroyed by fire (Beede, 1907, p. 142). Because of the growing recognition of the extreme importance of type specimens some paleontologists advocate abandonment of species for which the type specimens are lost, but the species considered here can be readily recognized. It appears that there is only one well-defined species of *Dozierella* in the Custer group, even though there is some variation in the large collections at hand.

The type specimens of *Cyrtodontarca? multidentata* (no. 165) and *C. ? parallelidentata* (no. 166) preserved in the collections of the University of Kansas Geological Museum are imperfect internal molds of *Dozierella gouldii*.

Occurrence: This is the most abundant species in the Custer fauna and commonly occurs in great numbers, generally associated with the only slightly less numerous Pleurophori. In Oklahoma and Texas the species is abundant wherever fossils are found in the Whitehorse sandstone (localities 1-10). A number of typical representatives of the species were found by Newell in the Azotea tongue of the Carlsbad limestone (locality 11). Insofar as known *Dozierella gouldii* does not occur elsewhere.

Family CONOCARDIIDAE

Genus *Conocardium* Bronn

Conocardium oklahomense Beede

(Plate 2, figures 2-4)

Conocardium oklahomaensis BEEDE, Oklahoma Geol. Survey, 1st Bienn. Rept., Advance Bull. (1902) p. 6, pl. 1, figs. 3-3c.
Conocardium oklahomaense BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 151, pl. 7, figs. 2-2f.

DESCRIPTION: Shell rather small for a *Conocardium*, about 17 mm. long and 7 mm. high in the largest specimen; equivalve, inequilateral; beaks subcentral and slender; anterior part of shell obliquely truncated at approximately 50 degrees to the hinge line, and flattened except where extended into an elongate tube at the hinge; anterior end ornamented by relatively fine, flattened radial costae; umbonal ridge separating anterior from posterior parts of shell prominent, flattened on the crest, and bounded on each edge by a more or less distinct costa; posterior part of shell extended into a rapidly tapering conical tube, evidently open at the extremity, ornamented by seven or eight relatively prominent costae, crossed by almost equally coarse concentric fila or lirae, spaced about the same interval as the costae.

DISCUSSION: This little form is extremely rare in the Custer fauna; the writers' collections contain only four fragmentary specimens, all from a single locality in northern Oklahoma. In spite of the imperfect and inadequate material the characters shown are sufficiently distinctive to readily distinguish this from most species of *Conocardium*. The present form is not readily comparable with other American species from the late Paleozoic, as it has relatively coarser ornamentation. The genus *Conocardium* is rarely represented in Permian rocks. Typical species of the genus, unlike the present species, however, are found in the Sosio beds at Palermo and in the Permian of Mongolia. The Kazanian species *C. tschernyschewi* Licharew is comparable to the Whitehorse form but may readily be distinguished by details of ornamentation and by the flattened umbonal ridge of the latter species. *Conocardium superstes* Healey and *Conocardium* ? sp. ind. Healey from the late Triassic of Burma certainly do not belong to this genus, and it is doubted that they should ever be referred to the Conocardiidae. Undoubted *Conocardium* is not represented in Mesozoic rocks; therefore the occurrence of typical *Conocardium* in the Custer group indicates that the enclosing rocks are Paleozoic in age. The type specimens of *C. oklahomense* from Whitehorse Springs were long ago destroyed by fire (Beede, 1907, p. 142).

OCCURRENCE: Very rare in the fossiliferous lens of the Whitehorse sandstone at Whitehorse Springs, west of Alva, Woods County, Oklahoma (locality 1). The species is thus far unknown elsewhere.

Family MYALINIDAE

Genus *Myalina* de Koninck

Myalina sp.

(Plate 2, figure 1)

Myalina sp. BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 156, pl. 7, fig. 7.
?Myalina squamosa? GIRTY, U. S. Geol. Survey, Prof. Paper 58 (1908) p. 429, pl. 16, fig. 22.

Beede discovered a fragment of a *Myalina* in the Whitehorse sandstone at Whitehorse Springs, Oklahoma, and there is another in the writers' collection from the

Dozier member in Texas, a nearly complete right valve retaining both external and internal molds. The species is shaped very like myalinas such as *Myalina meeki* Dunbar and has a marked forward obliquity, a relatively long hinge, and a nearly straight anterior margin which bounds a relatively slender, acute beak. Judging from the specimens at hand the shell, now completely gone, was originally very thin.

Although the internal mold is rather well preserved ligament grooves or a distinct ligament area are not visible.

DESCRIPTION: Shell relatively small, length, 15 mm., height, 12 mm., hinge length, 11 mm.; hinge margin intersects posterior margin at a rounded and somewhat indefinite angle of about 130 degrees, and the margins of the beak in the right valve diverge at about 50 degrees; although the anterior margin of the shell is almost straight the posterior margin is broadly curved, attaining the greatest convexity at the intersection with the anterior margin; surface of right valve nearly smooth.

DISCUSSION: Probably a separate specific name will ultimately have to be applied to this form. It is closely similar to *Myalina meeki* Dunbar from the lower Permian Wellington shale of Kansas but differs from that species in being relatively longer compared to the height and in having a subangular margin at the intersection of the anterior and ventral margins. Furthermore the posterodorsal margin of *M. meeki* is decidedly more angular than in the present form. The *Myalina* from the Custer is more like the *M. perattenuata* Girty (not Meek and Worthen) from the Lykins formation of Colorado but appears to have a relatively longer hinge line than the latter. The form described by Girty from the "dark limestone" bed of the lower Capitan of the Guadalupian section, and doubtfully referred to *Myalina squamosa* (Sowerby) (Girty, 1908, p. 429, Pl. 16, fig. 22), is externally more nearly like the Custer form than any other known to the writer. Girty's species certainly is not *Liebea squamosa* (Sowerby) [= *Liebea hausmanni* (Goldfuss)], of the European upper Permian, but probably represents an unnamed *Myalina*. However, since the hinge structures are unknown in the Guadalupian species its assignment to the proper genus cannot yet be certain.

The Custer form is probably a *Myalina,* as shown by an internal mold of the figured specimen, and does not show the critical characters of the ligament on which *Liebea* was founded by Waagen (1881, p. 292).

The genus *Liebea* needs a thorough investigation. *Liebea hausmanni* (Goldfuss) has long been regarded as a guide species of the Zechstein-Kazan faunas of western Europe and adjoining portions of the Arctic, yet it is not apparent that all of the specimens assigned to that species actually have the hinge characters of *Liebea* as interpreted by Waagen. For example, the hinge of Russian *Liebea* as illustrated by Maslennikov (1935, Pl. 2, fig. 11) seems to recall *Myalina* more than *Liebea*. The hinge of *Mytilus septifer* as illustrated by King (1850, Pl. 15, fig. 13) is certainly like that of typical *Myalina* and not at all like that supposed to characterize *Liebea;* yet *Mytilus septifer* is commonly classed as a *Liebea*.

Although the genus *Myalina* is represented chiefly in late Paleozoic rocks there are several citations to *Myalina* in the Triassic. A survey of the literature on Triassic myalinas reveals the fact that none of the species is similar to the Custer form.

OCCURRENCE: Extremely rare, represented in the Whitehorse Springs (locality 1) collections by one fragmentary specimen and by one fairly complete right valve from the Dozier lens of Texas (locality 7).

Family PARALLELODONTIDAE

Genus *Parallelodon* Meek

Parallelodon sp.

(Plate 2, figure 7)

DESCRIPTION: Shell relatively large, measuring about 35 mm. in length, and 17 mm. in height; relatively convex for a *Parallelodon;* elongate quadrate, with a well-defined posterior auricle terminating behind in nearly a right angle; auricle bounded below by a prominent umbonal ridge which extends backward to the sharply rounded, projecting posterior margin; ventral margin broadly convex on each side of a narrow sinus, which is located about one-third of the shell length behind the anterior margin; surface ornamented by closely spaced, fine radiating costellae, about 10 in the space of 6 mm.; costellae only slightly coarser on the posterior auricle than on the remainder of the shell; anterior portion of shell unknown.

DISCUSSION: This form is represented only by a single fragmentary external mold of a right valve. Probably it belongs to an unnamed species because the ornamentation is relatively fine as compared with other forms of equivalent size. However, the material is inadequate for the founding of a new species.

Parallelodon is a long-ranging genus, and the material at hand is too fragmentary to permit a detailed comparison with other species. The occurrence of *Parallelodon* in the Custer does suggest that the Custer fauna was at least derived from a normal marine facies, because this genus is almost invariably associated with typically marine faunas.

OCCURRENCE: Rare in the dolomitic facies of the Dozier lens; the writers' collections contain only one specimen from near Dozier, Texas (locality 6).

Superfamily OSTRACEA?

Genus *Gryphellina* Newell, n. gen.

Capulus Beede (in part), Kansas Univ. Sci. Bull., vol. 4 (1907) p. 170.

DESCRIPTION: Left valve unknown; right (upper ?) valve ventricose, gibbous, with protuberant and strongly overhanging prosogyrous beak; somewhat irregular in form,

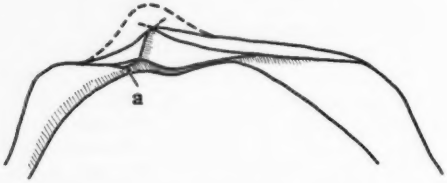

FIGURE 6.—*Hinge and ligament area in the new genus Gryphellina*

Camera lucida drawing. Hinge is quite similar to that of *Aviculopecten*. It is not certain whether *a* is a small lateral tooth or merely an accidental feature.

suggesting a fixed habit for the left valve; obscurely auriculate, without a well-defined byssal sinus; surface of umbo ornamented with regularly spaced concentric fila or lirae; body of shell cancellated with intersecting costellae and lirae; hinge

comparable to that of *Lima* or *Ostrea,* consisting of an edentulous, broad and smooth hinge plate with a central, obliquely triangular resilifer which is elongated posteriorly as in *Aviculopecten.*

GENOTYPE SPECIES: *Capulus sellardsi* Beede.

DISCUSSION: The significant characters of this genus are believed to be the highly convex, rostrate right valve with an obsolescent, nearly indistinguishable byssal sinus, and the very fine cancellated ornamentation. The hinge characters might equally well suggest relationship with either the Aviculopectinidae or Ostracea. Inasmuch as all the Aviculopectinidae have a relatively flat right valve, a well-defined byssal notch, and invariably lay at rest on the right valve, the present form can scarcely be referred to that group. On the other hand members of the Ostreidae lie at rest on the left valve. It is true that the right, or upper valve in such typical genera as *Exogyra* and *Gryphaea* is flattened and operculiform and not at all gibbous as in the present genus. Therefore *Gryphellina* cannot properly be referred to the Ostreidae. If indeed the new genus is one of the Ostracea it may ultimately be necessary to erect a new family for its reception. The writer knows of no other pelecypod genus with which it can be compared.

Gryphellina sellardsi (Beede)

(Plate 1, figures 8-13)

Capulus sellardsi Beede, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 170, pl. 7, figs. 8-8f.

DESCRIPTION: Left valve unknown; right valve deeply convex, somewhat irregular in form, slightly higher than long, with gibbous protuberant beak extending over the hinge to the plane of commissure; hinge line short, auricles small and poorly defined, anterior one bounded outwardly by a shallow nearly obsolete byssal sinus; anterior slope of umbo markedly concave, giving the beak a prosogyre curvature; posterior umbonal slope slightly concave to convex; surface marked by very fine costellae, most distinct and numerous on the umbo where 20 to 40 occur in a space of 5 mm., thence dropping out or becoming very obscure toward the shell periphery; concentric fila, or lirae, ornament the entire surface in some specimens and are spaced more or less regularly at intervals slightly greater than the interspaces between costellae, in other specimens being spaced quite irregularly; hinge as in Ostreidae or Aviculopectinidae, with a well-defined, broad and smooth hinge plate, at the center of which occurs a triangular resilifer with marked forward obliquity; musculature and shell microstructure unknown.

Shell measurements in Gryphellina sellardsi

Specimen	Height (mm.)	Length (mm.)	Convexity (mm.)	Hinge length (mm.)
1	21	20	9	10±
2	23	19	5	....
3	20	18±	5	10+
4	17	16	6.5	....
5	26	25	10	12
6	23	20	6.5	13±
7	6	5	3	....
8	25	17	12	9±
9	20	20	7	....
10	24	18	7	11±

DISCUSSION: The writer knows of no Permian or Triassic shell similar to this one. Although there is a superficial resemblance between the present form and some species of *Pseudomonotis, Clairaia,* and *Exogyra* it differs from all of these in the

marked convexity of the right valve. The curvature of the umbo to the right, as viewed externally, and the left hand obliquity of the resilifer, as viewed on the inside of the shell, leave no doubt that these are indeed right valves. The marked convexity of the shells suggests that the opposite valve was flat, or nearly so, and the irregular growth suggests a fixation of the left valve comparable with the cementation of the right valves of *Pseudomonotis*. The lack of a deep byssal notch in these right valves certainly excludes the present form from the Aviculopectinidae. Typical Ostreidae live with the left valve undermost, and commonly, as in *Ostrea*, the lower valve is cemented firmly to the substratum.

Although the holotype of *Gryphellina sellardsi* is supposed to be located at the University of Kansas Geological Museum, it appears to be lost.

Occurrence: Relatively common in the sandstone lens at Whitehorse Springs, Oklahoma (locality 1). Rare in the Dozier member in northwestern Texas (localities 4-9).

Family Trigoniidae

Genus *Schizodus* (King) De Verneuil

Schizodus King, Ann. and Mag. Nat. Hist. (1844), p. 313 *(nomen nudum)*; De Verneuil, Bull. Soc. geol. France, 2me Ser., vol. 1 (1844), p. 505; Cossmann, Ann. Paleontologie, vol. 7 (1912), p. 9; Crickmay, Amer. Jour. Sci., vol. 24 (1932), p. 454. Genotype: *Schizodus schlotheimi* (Geinitz), from the German Zechstein.

Many citations appear in the literature of occurrences of *Myophoria* in Paleozoic rocks and *Schizodus* in the Triassic system. An extended survey of the literature on these genera indicates that information on most of the species in question is entirely inadequate to make a satisfactory generic assignment. There is a surprising lack of agreement regarding the generic characters of *Myophoria* and *Schizodus*. Among the scores of Carboniferous and Permian species described as *Schizodus*, the cardinalia of only a few have been described at all, and even fewer are adequately illustrated. Probably all of the Lower Carboniferous trigoniids and many of the Upper Carboniferous forms belong to De Koninck's *Protoschizodus*, which is distinguished from *Schizodus* mainly on hinge characters.

Part of the misunderstanding of these primitive trigoniid genera is due to unfortunate statements in the Eastman-Zittel *Textbook of paleontology*, in which, for example, *Myophoria* is said to have the "lateral teeth fluted"—*i. e.*, cardinal teeth striated, as in *Trigonia*, and the characteristic trigoniid genus *Protoschizodus* is classed with the Astartacea.

Considering our imperfect knowledge of the Paleozoic Trigoniidae the classification and phylogeny by Cossmann (1912) is probably the most satisfactory to date. According to Cossmann's investigations undoubted *Schizodus* does not occur in Mesozoic rocks, and *Myophoria* is not known in the Paleozoic.

A small trigoniid is relatively common in the Whitehorse sandstone in Oklahoma and Texas, although nowhere abundant. Originally described as *Schizodus? oklahomensis* Beede it is not wholly like typical *Schizodus*, nor is it a *Myophoria*, although certain features of the musculature and ornamentation suggest the latter genus. Remarkably like the Custer species is *Schizodus praecox* (Waagen) described from the uppermost zone of the *Productus* Limestone of late Permian age in India. (*See* Plate 1, figure 7.) Waagen regarded his species as a representative of *Myophoria*.

It appears to the writer that the Indian species and the American form are relatively advanced forms, approaching *Myophoria* more closely than do most other species of *Schizodus*. The two species are certainly congeneric and are so nearly

identical in many characters as to suggest that they represent the same geologic age—*i. e.*, latest Permian.

Schizodus oklahomensis Beede

(Plate 1, figures 1-6)

Schizodus? oklahomensis BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 157, pl. 7, fig. 6.

Schizodus ovatus Meek and Worthen? BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 157, pl. 7, figs. 7-7b.

DESCRIPTION: Valves a little longer than high, beaks only slightly opisthogyre and located about one-third of shell length behind anterior margin; anterior margin semicircular, ventral margin evenly convex, terminating posteriorly in a rounded angle of about 90 degrees where the rear margin of the shell presents a truncated appearance; posterior margin nearly straight, merging with the hinge line in a rounded, broadly obtuse angle of 130-140 degrees; a conspicuous, rounded to subangular ridge extends in a sweeping curve, concave dorsally, from the beaks to the posteroventral angle of the margin, being the junction between the lateral surface of the valves and a somewhat flattened and differently ornamented posterodorsal area; this area is approximately bisected by one, possibly more, narrow and rather obscure costa, which extend from beaks to the center of the posterior margin; entire valve ornamented by rather conspicuous, narrow, uniformly spaced concentric lirae, or fila, which are least conspicuous on the posterodorsal (siphonal) area; lirae spaced about 10 in 5 mm. near the venter of mature valves.

Shell measurements in Schizodus oklahomensis

Specimen (valves)	Length (mm.)	Height (mm.)	Convexity (mm.)
1. Left, internal mold	23	17	4
2. Left, internal mold	16.5	12	3
3. Right, external mold	18	14	4
4. Left, shell	12	9	3

The dental formula, after the system of Bernard and Munier-Chalmas, for immature individuals is $\frac{\text{R} \quad 3a : 3b}{\text{L} \quad 4a : 2 : 4b}$. This formula applies equally well to *Schizodus* or *Myophoria*, the principal difference between the two genera being that tooth No. 2 is supposed to be markedly bifid in *Schizodus*, whereas the corresponding tooth in *Myophoria* shows no bilobation at all. In the present species No. 2 is slightly bilobed but not distinctly bifid; 4a is well developed, but in mature individuals 4b becomes obsolete, unlike typical *Schizodus*. The teeth 3a and 3b are strong and widely divergent, the former being extraordinary in being slightly bilobed as in No. 2 and in being markedly thicker and more massive than 3b.

In the right valve there are two cardinal teeth, of very unequal size; the front one—No. 3a—lies slightly ahead of the beak, is relatively large, projecting into the other valve and extending obliquely forward at an angle of approximately 45 degrees with the hinge axis; termination of tooth slightly expanded and wedge-shaped rather than triangular, flattened on the anteroventral and posterodorsal faces; terminus of tooth slightly bilobed, owing to a shallow furrow along the center of the anteroventral face; No. 3a bounded anteriorly by a narrow, linear socket, which lies next to and is approximately parallel with the anterodorsal margin of the shell; posterior tooth No. 3b, much more slender than 3a, is decidedly lamellar, extending backward as a narrow ridge lying at a small angle with the shell margin, with axis

approximately parallel to the wedge-shaped end of 3a; socket between 3a and 3b poorly defined, not excavated into hinge plate, being bounded principally on two sides by the juncture of the teeth where they form an angle of only slightly more than 90 degrees; posterior adductor scar in right valve barely distinguishable, imme-

FIGURE 7.—*Dentition of Schizodus oklahomensis Beede*

Camera lucida drawings. *A*, Left valves, showing reduction of median groove of tooth No. 2, and apparent loss of tooth No. 4b at maturity. *B*, Right valves, showing bilobed character of tooth No. 3a.

diately below the posterior end of the hinge plate, and slightly larger than the anterior one; anterior impression subelliptical, vertically elongated, extended dorsally onto the hinge plate in a slender muscle furrow; pallial line relatively close to the shell margin.

In the left valve there are three cardinal teeth in immature individuals, tooth 4b being obscure or wanting in full-sized individuals; No. 2 relatively large and conspicuous as compared with the other two, situated almost directly under the beak, more or less flattened at its termination so that the wedge-shaped edge diverges anteriorly from the hinge axis at about 45 degrees, whereas the axis of the tooth is inclined backwards, forming an acute angle posteriorly with the hinge axis; obscurely bilobed by a shallow furrow along the midline of the ventral surface; 4a lamellar, well-defined, lying just within and slightly divergent from the valve margin, well in advance of the beak, with axis about parallel, or very slightly divergent to the flattened terminus of No. 2; 4b lamellar, short, lying near and almost parallel to hinge margin, becoming gradually broader posteriorly, merging distally with the ventral margin of the hinge plate, and separated from No. 2 by an elongate triangular socket; 4b obsolescent or lacking in large shells; socket between 2 and 4a without a well-defined floor, being simply the space between the projecting prongs of the teeth; adductor scars in left valve projected dorsally in narrow impressions or furrows at the extremities of the hinge plate, the anterior one in particular being bounded behind by a rather narrow and relatively obscure ridge or buttress, best seen in mature specimens; pallial line and shape of adductors in left valve not observed.

DISCUSSION: The assignment of this species to *Schizodus* is not wholly satisfactory, chiefly because it is none too certain what latitude should be ascribed to *Schizodus*. In some respects the present form is like *Myophoria* but the dental structures are as unlike typical *Myophoria* as typical *Schizodus*. The genus *Schizodus*, as diagnosed by King (1850), has a bifid middle tooth—No. 2—in the left valve, with massive, strongly divergent prongs. Since the corresponding tooth in *Myophoria* is not bilobed or bifid the writer's species is more like *Schizodus* but cannot be regarded as typical of that genus. The flattened ends of No. 2 and No. 3a are not like any described *Schizodus* or *Myophoria*, nor is the obsolescent character of 4b characteristic of either genus. The ornamentation of *Schizodus oklahomensis* is more nearly reminiscent of *Myophoria* than of *Schizodus*, as is the high level at which the adductor muscles are placed. However, the weak development of the buttress behind the anterior adductor and the slightly opisthogyre obliquity of the beaks are more like *Schizodus*. The opisthogyre beaks and bifid No. 2 tooth of the left valve in *Schizodus* are features of specialization, even beyond *Myophoria;* the beaks in the latter genus are typically orthogyre, and the No. 2 cardinal tooth is never divided. In these respects *Schizodus* is more like *Trigonia* and may be the direct ancestor of the later genus. The simple teeth and orthogyre beaks of *Myophoria* are reminiscent of similar features in *Protoschizodus*, and it may be that the latter genus instead of *Schizodus* is the immediate ancestor of *Myophoria*. Further study of the late Paleozoic trigoniids is necessary before these questions can satisfactorily be answered.

A close resemblance exists between *Schizodus oklahomensis* and a species from the late Permian Upper *Productus* Limestone of the Salt Range (Pl. 1, fig. 7), described by Waagen (1881, p. 243-244, Pl. 19, figs. 17-19) under the name *Myophoria praecox*. The two species are almost identical in form, ornamentation, high placement of the adductor impressions, and in the development of a low buttress ridge behind the anterior adductor (regarded by Waagen as the special generic characteristic of *Myophoria)*. Unfortunately Waagen did not make sufficiently detailed remarks concerning the hinge in *M. praecox*, so that a satisfactory comparison of the hinge in the two species cannot be made. Apparently the Indian species lacks the external costa on the posterodorsal area possessed by *S. oklahomensis*.

The holotype of *S. oklahomensis* is located in the collections of the University of Kansas Geological Museum (type number 170).

OCCURRENCE: Rare in the lower Whitehorse sandstone at Whitehorse Springs, Oklahoma, locality 1 (holotype); common in the Dozier dolomite, Collingsworth, Wheeler, and Hall counties, Texas (localities 4-9).

The species is more abundant in the relatively pure dolomite facies and is less common in the red dolomitic sandstone.

Family AVICULOPECTINIDAE

Genus *Aviculopecten* McCoy

Aviculopecten vanvleeti Beede

(Plate 2, figures 14-17)

Aviculopecten vanvleeti BEEDE, Oklahoma Geol. Survey, 1st Bienn. Rept., Advance Bull. (1902) p. 6, pl. 1, figs. 8-8b.

Aviculopecten vanvleeti BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 159, pl. 5, figs. 2-2e.

Aviculopecten oklahomaensis BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 158, pl. 5, figs. 3-3c; pl. 6, figs. 11-11c.

Aviculopecten vanvleeti NEWELL, Kansas Geol. Survey, vol. 10 (1938) p. 57, pl. 5, figs. 8-10.

DESCRIPTION: Shell of moderate size, higher than long, attaining a height of 52 mm. and length of 48 mm. in the largest specimen; somewhat variable in outline, generally, however, with a pronounced forward obliquity; posterior auricle slightly shorter and smaller than the anterior one, the former commonly quadrate or subquadrate, although in a few specimens slightly extended posteriorly; umbonal angle relatively narrow, in most specimens (left valves) ranging from about 70 to 75 degrees; posterior umbonal fold poorly defined, although there is a rather well-defined sulcus at the inner margin of the rear auricle, setting it off from the highly convex umbo; anterior umbonal fold and sulcus well defined and nearly straight in most specimens; obscure radial sulcus occurs just within the posterior margin of shell body and in front of auricle, recalling a similar but more pronounced lobation seen in *Pseudomonotis;* from three to five of the primary costae across the middle of the shell relatively coarse, with a knobby appearance produced by short spines or projecting imbrications of the shell; bounding costae of the shell body at juncture with auricles not particularly coarse; spaces between largest costae occupied by 6 to 10 closely spaced, fine, subequal costae in medium-sized specimens, 15 to 22 in large ones where another rank of intercalaries is added between the more robust costae; some of the costae show a gerontic tendency in large individuals to bifurcate distally; total number of body costae ranging up to about 80 in large individuals; auricles covered with fine, subequal costae, anterior ones ranging in number from about 8 in half grown individuals to 20 in large specimens; hinge, as in other aviculopectens, provided with a broad, massive hinge plate, excavated near the center by a shallow triangular resilifer having a slight forward obliquity.

DISCUSSION: The species *A. oklahomensis* Beede is included in the synonymy of *A. vanvleeti* because the holotype of *A. oklahomensis* appears to be a specimen of *A. vanvleeti* in which the ornamentation is poorly preserved, and therefore indistinct. It is true that a few specimens in the writers' collections lack the coarse ornamentation of typical *A. vanvleeti* and the writer would be disposed to regard them as representatives of a separate species were it not for the fact that they occur in the same beds with typical *A. vanvleeti* and intergrade completely with the latter forms.

The stratigraphic range of *Aviculopecten* has been discussed at length elsewhere (Newell, 1938, p. 44). It is enough here to state that citations to *Aviculopecten* in the Triassic are not substantiated by detailed observations of the hinge characters. Therefore, although *Aviculopecten* may occur in the Triassic, verification is needed.

Aviculopecten vanvleeti, although similar in a general way to aviculopectens at various horizons of the late Paleozoic throughout the world, is not to be confused with any other species known to the writer.

The holotype of *A. vanvleeti* was destroyed by fire (Beede, 1907, p. 142). The types of the synonymous *A. oklahomensis* (Nos. 171A-H) are at the University of Kansas.

OCCURRENCE: Relatively common in the Whitehorse Springs lens (locality 1) and in the Dozier lens (localities 4-9) of the Whitehorse sandstone formation.

Family AMUSSIIDAE

Genus *Pernopecten* Winchell

Pernopecten symmetricus Newell, n. sp.

(Plate 2, figures 9, 10)

DESCRIPTION: Left valve of medium size, measurements of largest specimen, a left valve, being: height, 26 mm.; length, 23 mm.; hinge length, 11 mm.; form subcircular, with only an obscure suggestion of a marginal antero- and postero-dorsal angulation below the auricles; auricles small, subequal, with an obscure anterior byssal

sinus; dorsal margin extraordinary in being nearly straight, with only a slight projection of the auricles above the hinge line; basal margin of auricles diverging along well-defined, slightly concave unbonal ridges at about 105 degrees; anterior and posterior areas of the body of the shell flattened, umbonal area slightly convex; right valve unknown.

DISCUSSION: The discovery of *Pernopecten* in the Custer fauna is something of a surprise and has important bearing on interpretations of the age and ecology of the fauna. The genus *Pernopecten* does not occur in Mesozoic rocks insofar as can be determined but is there replaced by the derived genus *Entolium*, which differs from *Pernopecten* in the nearly perfect symmetry of the valves, and in the smaller, almost nonprojecting auricles of the left valve. Although *P. symmetricus* approaches *Entolium* rather more closely than do many species of *Pernopecten*, it has the *Pernopecten* characteristic of unequal auricles, and the byssal sinus is recognizable, a feature that seems to be absent in typical *Entolium*.

Pernopecten symmetricus differs from other late Paleozoic representatives of the genus in lacking the truncated posterior margin so characteristic of most of the species and in having a relatively long hinge line as compared with other species. The auricles do not extend very high above the hinge line, resembling in this respect representatives of *Entolium* more than some of the pernopectens.

All the pernopectens as well as Mesozoic and Cenozoic Amussiidae occur in rocks indicative of a marine environment. *Pernopecten* does not occur, to the writer's knowledge, in brackish water, or otherwise abnormal faunas.

It is worthy of note that *P. symmetricus* is not closely akin to the Capitan *Pernopecten obliquus* Girty.

The holotype of *P. symmetricus*, located at Yale University, Peabody Museum (No. 16,328), is a well-preserved internal mold.

OCCURRENCE: Rare in the Dozier dolomite of northwestern Texas (localities 7 and 9).

Family PECTINIDAE

Genus *Pseudamusium* Adams

Pseudamusium? sp.

(Plate 2, figures 11-13)

In the collections from the Dozier dolomite of the Whitehorse sandstone in northwestern Texas there are three small, poorly preserved pectinids, preserved as internal molds. There is no trace of the shell surface, but it is likely that the shells were originally unornamented. Although the specimens are too poorly preserved for a specific or even a generic determination the writer is convinced that they are not aviculopectinids but should be referred to the Pectinidae. The imprint of a median resilifer is to be observed at the center of the hinge in the specimens at hand, and it appears that the resilium was an internal organ, quite unlike the external resilium of *Aviculopecten*. Elsewhere (Newell, 1938) the writer has tried to show that undoubted representatives of the Pectinidae are not known in the Paleozoic, the numerous references to *Pecten*, *Pseudamusium*, and other Pectinidae in the Paleozoic applying to shells in which the hinge characters are not known, or else to specimens having hinge structures quite unlike the post-Paleozoic pectinids. Therefore the discovery of a typical member of the Pectinidae in the Custer fauna is an important one, even though a positive generic and specific determination cannot be made.

The anterior auricle in the specimens at hand is slightly longer than the posterior one, and the latter auricle is small with an obtuse termination. The specimens are all small, having a height ranging from 6 to 9 mm., and a length of from 5 to 9 mm.

DISCUSSION: It is not fruitful to try a detailed comparison of this form with the other species in which the hinge characters are not known. With this one exception, undoubted representatives of Pectinidae from Paleozoic rocks are not known to the writer. Similar forms like *"Streblopteria" tenuilineata* (Meek and Worthen) belong to a separate family—the *Aviculopectinidae*—apparently an exclusively Paleozoic family characterized by distinctive hinge features, which unfortunately are often neglected. For that matter very few of the Triassic pectinids are adequately known. Most of the Triassic forms referred to *Pseudamusium, Pecten,* and *Aviculopecten* are classified on external characters of form that actually do not invariably serve to positively distinguish genera that are internally quite different.

For the present it is important to note the occurrence of this small typical member of the Pectinidae in the Custer fauna, associated with genera that indicate a Paleozoic age for the enclosing rocks.

OCCURRENCE: Very rare in the dolomitic facies of the Dozier dolomite of northwestern Texas (locality 7).

Family PHOLADELLIDAE

Genus *Allorisma* King

Allorisma? albequus Beede

(Plate 2, figures 8, 22, 23)

Allorisma? albequus BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 160, pl. 7, figs. 5-5c.
? Edmondia? bellula GIRTY, U. S. Geol. Survey, Prof. Paper 58 (1908) p. 420, pl. 9, figs. 22-22b.

DESCRIPTION: Shell equivalve, exceedingly small for an *Allorisma,* measuring around 5 mm. in length and 3 mm. in height; roughly subcylindrical in form, less convex posteriorly; characterized by a rather prominent, projecting anteroventral lobe, which is bounded posteriorly by a broad, shallow sulcus extending from umbones posteroventrally to the ventral margin, where it forms a sinus whose broad apex is approximately one-third of the shell length behind the anterior margin; surface ornamented by low, poorly defined concentric undulations; posterior border nearly semicircular; hinge edentulous; musculature and pallial line not observed.

DISCUSSION: Perhaps this species should be referred to some other genus than *Allorisma.* Since the shell surface was not observed and the characters of the pallial line could not be distinguished, the assignment of this species to *Allorisma* must be considered as tentative. A very similar and probably closely related species was described from the Capitan limestone of the Guadalupe Mountains by Girty under the name *Edmondia? bellula.* The resemblance between the two species may, however, be more apparent than real.

Apparently there is no Triassic form with which the present one might fruitfully be compared. Neither *Edmondia* nor *Allorisma* are known in post-Paleozoic rocks. The type specimen, here designated lectotype, is located at the University of Kansas Geological Museum (No. 173-G).

OCCURRENCE: Rare in the fossiliferous lens at Whitehorse Springs, Oklahoma (locality 1) and in the Dozier lens in northwestern Texas (localities 4-9).

Allorisma rothi Newell, n. sp.

(Plate 2, figures 5, 6)

Solenomya sp. BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 150, pl. 5, fig. 4.

Shell relatively small, measuring 8 mm. high, and about 20 mm. long in the largest specimen; equivalve; dorsal and ventral margins approximately straight and parallel; posterior margin broadly rounded, anterior margin narrowly rounded, extended well

in front of the umbones; beaks probably orthogyre, located about one-fourth to one-fifth of the shell length back of the anterior margin; surface ornamented with relatively broad and flattened concentric undulations which become crowded at both extremities of the shell; especially distinguished by a relatively narrow, distinct, unornamented sulcus which extends backward from the beaks just under the hinge line, gradually becoming broader until it intersects the posterior margin about one-third of the distance down from the hinge line; surface ornamented in quincunx arrangement with microscopic papillae, which occur in radial rows extending downward from the beaks; valves only moderately convex; hinge edentulous.

Discussion: This species is clearly related to the Pennsylvanian *Allorisma subelegans* Meek and *A. reflexa* Meek but is notably longer than the former and has a distinctly straighter ventral margin than either of those species. This form is not comparable with any Triassic species known to the writer.

The holotype (No. 20,796) is preserved in the Geological Museum at the University of Wisconsin.

Occurrence: Rare in the Whitehorse Springs lens (locality 1) and in the Dozier lens of the Whitehorse in Oklahoma and Texas (localities 7, 9).

Family Pleurophoridae

Genus *Pleurophorus* King

The genus *Pleurophorus* was founded on the species *Arca costata* Brown, which King believed to possess two cardinal teeth under the beak in each valve, as well as a lamellar, posterior lateral tooth situated near the dorsal margin of the posterior end of the left valve. To demonstrate these characters of dentition King (1850, Pl. 15, figs. 16-19) figured drawings of the interior of complementary valves of an adult individual and a juvenile from "Byers Quarry" at Suter Point, Durham, England, from the upper Magnesian Limestone, of Zechstein age. The drawings of *Pleurophorus costatus* are convincingly executed and leave no doubt regarding the exact nature of the structures that King regarded as significant in establishing *Pleurophorus*.

Although *Pleurophorus costatus* is said to be relatively common in the English Permian and observations on the hinge have been made by several investigators it appears that no one has succeeded in verifying King's observations. On the other hand the hinge of *Pleurophorus* as normally expressed in *P. costatus* is quite different from the kind of hinge that King described.

The problem of *Pleurophorus* was reinvestigated by J. Böhm (1914). Securing specimens that he regarded as authentic topotypes of *P. costatus* Böhm made detailed observations on the dentition of the species and published drawings to substantiate his statements. He denied the existence of two cardinal teeth in each valve but found only one, with corresponding sockets, in each valve. In an excellent specimen from Tunstall, England, retaining both valves, he found that the shell is thick, becoming somewhat thinner posteriorly.

"The beaks are markedly prosogyre, and markedly curved inward and forward. The shell reaches its greatest height not under, but just behind the beaks. The lunule is small, clearly outlined and deepened, the fulcrum moderately long. The anterior adductor muscle is bounded behind by the very strongly developed muscle buttress, which extends up to the level of the hinge plate.

"On the small hinge plate of the right valve is the stout cardinal tooth, extending almost parallel to the hinge border. The posterior hinge border is elevated to a slender lateral tooth which is received by a corresponding furrow in the opposite valve.

"In the left valve a deep socket serves to receive the right cardinal tooth, and is bounded dorsally by the ligament area, ventrally by a hinge tooth." (Böhm, 1914, p. 555, free translation.)

Böhm appealed to Dr. F. L. Kitchen of London for information regarding King's original specimens that served as a basis for the original diagnosis of the genus. Kitchen's search failed to locate these specimens in any of the English museums.

The curators of the British Museum of Natural History have generously lent specimens of *Pleurophorus costatus* from the Magnesian Limestone. In many respects these specimens are closely akin to those illustrated by King and Böhm as regards form and ornamentation. Although the hinge characters are not particularly well shown one internal mold shows clearly that the valves possessed only one cardinal tooth each.

There is no alternative, it seems, but to assume that the original diagnosis of *Pleurophorus* was erroneous and did not truly describe the significant characters of dentition possessed by the genotype.

The forms from the Whitehorse sandstone described below are similar to *Pleurophorus costatus* as described by Böhm; the writer is therefore confidently assigning the material at hand to *Pleurophorus*.

Brief mention here should be made of the Permian genus *Pleurophorina* Licharew (1925, p. 125) from the Russian Kazanian beds. Like the Custer representatives of *Pleurophorus* Licharew's genus is characterized by the possession of fine external papillae radiating in rows outward from the beaks toward the periphery. It seems probable, as Licharew has indicated, that the papillate surface of the shell should not be regarded as of generic significance. Although papillae have not generally been noted in species of *Pleurophorus*, at least two species in addition to the present ones have been described with this feature. *Pleurophorus immaturus* Herrick and *P. spinulosus* Morningstar (Morningstar, 1922, p. 236-240) from the Pottsville horizons in Ohio exhibit papillate ornamentation like the Whitehorse specimens.

Pleurophorina is supposed to differ from *Pleurophorus* in the lack of a cardinal tooth in the left valve, but Licharew's photographs of squeezes do not illustrate this feature convincingly. Artificial casts of these shells made by pressure are commonly misleading, and it may be that *Pleurophorina* is not so different from *Pleurophorus* as might first appear.

None of the so-called *Pleurophorus* species from the Triassic has the general physiognomy of the Whitehorse forms, which, on the other hand, are obviously closely akin to other late Paleozoic Pleurophori.

Pleurophorus albequus Beede

(Plate 3, figures 1, 4-8, 14, 16-18)

Pleurophorus sp. Beede, Oklahoma Geol. Survey, 1st Bienn. Rept., Advance Bull. (1902) p. 9, pl. 1, fig. 4.

Pleurophorus? albequus Beede, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 160, pl. 6, figs. 8-8e.

Description: Valves markedly elongate, relatively flattened, with a broad but well-defined sulcus extending posteroventrally almost to the middle of the ventral margin, producing a modioloid anterior lobation and a ventral sinus; anteroventral lobe less convex than posterior part of shell and marked by rugose growth lines and fine, irregularly disposed papillae; sulcus bounded posteriorly by a broad, but well-defined umbonal fold, about coincident in area to the entire posterior portion of the shell, and is marked by three to six obscure radial costellae; dorsal margin broadly and slightly convex; ventral margin broadly indented at a sinus which corresponds to the sulcus; rear margin almost but not quite semicircular, with greatest convexity of curvature near midpoint of margin.

Shell measurements in Pleurophorus albequus

Specimen (valves)	Height (mm.)	Length (mm.)	Convexity (mm.)
1. Right	5.5	12.5	2+
2. Right	9.0	21.0	4.0
3. Right	7.5	16.5	3.0
4. Left	4.5	11.5	1.5
5. Left	7.0	15+	—

Dentition consists of one cardinal and one lateral tooth in the left and one cardinal tooth in the right valve; cardinal of right valve elongate-triangular, situated just

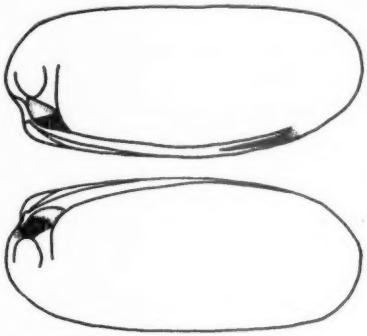

FIGURE 8.—*Diagrams illustrating hinge of Pleurophorus albequus Beede*

Sockets are indicated by black.

behind the beak, with apex directed toward the beak, and with margin of tooth and underlying socket nearly horizontal; socket roughly triangular, apex under the beak, with opposite side concave for the reception of curved margin of complementary tooth of opposite valve; lamellar dorsal margin of right valve serves as tooth, fitting above lateral tooth of left valve; left valve provided with one subtriangular cardinal tooth, with apex under the beak, and the opposite side straight or slightly curved, either concave or convex, separated from the hinge margin by a well-defined triangular socket; narrow posterior lateral tooth, separated by an equally narrow furrow parallel to hinge margin, and terminating about one-fourth of the shell length in front of the posterior margin of the shell; anterior adductor impression ovoid, deep, located directly under the beak about midway above ventral margin, separated from main visceral cavity of shell by a robust, elevated buttress; posterior adductor subcircular, shallow, about same size as anterior scar, located immediately under posterior end of lateral tooth; pallial line parallel to ventral margin and located from one-fifth to one-fourth of the shell height above the margin; lunule and escutcheon well defined; ligament external, located just behind beaks, apparently about half as long as the escutcheon.

DISCUSSION: *Pleurophorus albequus* more closely resembles the English Permian *P. costatus* in form than the American Pennsylvanian representatives of the genus,

yet it is considerably smaller than the European species, and the ornamentation is less distinct. The Custer specimens appear to be distinctly longer than those from the English Permian.

The types of *P. albequus* (Nos. 174 A-C) are located in the Geological Museum at the University of Kansas.

Occurrence: Abundant in the Verden (locality 3), Whitehorse Springs (locality 1), and Woodward (locality 2) lenses of the Whitehorse sandstone in Oklahoma, and abundant in all outcrops of the Dozier lens (localities 4-10) in northwestern Texas. Rare in the Azotea tongue of the Carlsbad limestone near Lakewood, New Mexico (locality 11). Next to *Dozierella gouldii* this species is the most abundant fossil in the Whitehorse sandstone, being found in all fossiliferous outcrops of the formation in Oklahoma and Texas.

Pleurophorus albequus longus Beede

(Plate 3, figures 2, 3, 15, 19-23)

Pleurophorus? albequus longus Beede, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 162, pl. 6, fig. 9.

Description: Shell relatively elongate, flattened laterally or moderately convex; unornamented, or with only obscure traces of radial costae; posterior margin of distinctive form, nearly straight, intersecting hinge line obliquely at a broadly obtuse angle; umbonal fold obscure or lacking; broad obscure sulcus extending from beaks to point just in front of middle of ventral margin, or absent in some specimens; hinge as in *P. albequus*.

Measurements of internal molds of Pleurophorus albequus longus

Specimen	Height (mm.)	Length (mm.)	Convexity (mm.)
1	8.5	25+	2+
2	6+	17	2+
3	7	19	2+
4	6	20	2
5	6.5	17	2
6	9	27	3
7	6	16.5	2+
8	6	15+	2+
9	7	18	2
10	12+	35	4

Discussion: Although this form is generally easily distinguished from *P. albequus* the two are invariably associated in the same beds. Closely related species of a genus are seldom found living together in modern faunas and ordinarily the writer has taken the view that similar forms of a single genus found together in the rocks are probably conspecific. Although this logic is based on purely circumstantial evidence, it represents a conservative view that has the obvious merit of limiting the number of species that might be recognized in any fossil fauna. It may be that the two forms of *Pleurophorus* found in the Whitehorse beds are dimorphic representatives of a single species. Sexual dimorphism is not common in pelecypods, but many instances are actually known in modern forms.

The holotype is No. 175 of the type collections in the Geological Museum, University of Kansas.

Occurrence: Whitehorse Springs lens in northern Oklahoma (locality 1), and Dozier lens in northwestern Texas (localities 4-9), both horizons lying in the Whitehorse sandstone.

VERMES

Family SERPULIDAE

Genus *Spirorbis* Daudon

Spirorbis sp.

Spirorbis sp. Beede, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 148, pl. 6, fig. 10.

Several poorly preserved internal molds of a small *Spirorbis* occur adherent to other shells. Chiefly they were attached originally to the inner surface of pelecypod shells. The largest specimens have a diameter of about one millimeter across the disc of coiling.

OCCURRENCE: Common in the Whitehorse Springs lens (locality 1) and in the Dozier lens of the Whitehorse sandstone (localities 4-10) in Oklahoma and Texas.

GASTROPODS OF THE WHITEHORSE SANDSTONE

BY J. BROOKES KNIGHT

Superfamily TRYBLIDIACEA

Family METOPTOMATIDAE

Genus *Lepetopsis* Whitfield, 1882

GENOTYPE, by original designation, *Patella levettei* White, (1882).

Lepetopsis? haworthi (Beede)

(Plate 4, figures 1a-b)

Capulus? haworthi BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 169, pl. 8, figs. 12-12b

DESCRIPTION: Small, strongly convex, patelliform gastropods, with a blunt apex rather strongly directed toward one end, here arbitrarily regarded as posterior, but not overhanging it; anterior slope rather strongly convex; posterior slope below the apex gently concave; lateral slopes nearly flat; aperture with well-rounded anterior and posterior margins and more gently rounded sides, slightly longer than wide, with the apertural plane longitudinally gently arched upward in the middle; ornamentation well marked, slightly fasciculated lines of growth and very fine radiating lirae; muscle scars unknown. The holotype, a steinkern, measures about 5 mm. longitudinally across the aperture with a width of about 4 mm. and a height of about 4 mm. A paratype, an external mold, is of similar size.

DISCUSSION: Beede's holotype is a steinkern or internal mold of the shell. The left side which is fairly well preserved seems to show a slight irregularity in the apertural margin, the significance of which is unknown. No trace of a muscle is to be seen. Both of these features unless they are accidental would militate against including the species in *Lepetopsis*. However, since a marginal irregularity may well be accidental and since the shallow muscle scars of small, thin shells are often not preserved, both are discounted. The hypotype is a sharp external mold and yields an excellent wax squeeze. It shows the external features nicely, and a perfectly smooth and gently arched apertural margin on the right side. The left side of the margin is not preserved.

The genus *Lepetopsis* has little stratigraphic significance other than late Paleozoic, and there is so little distinctive about it that with poor specimens it might readily be mistaken for similar genera of almost any geological age. The species is similar in size to *Patella capitanensis* Girty, 1908, which is probably referable to *Lepetopsis*, but its strongly recurved apex and much finer radiating lirae distinguish it.

OCCURRENCE: Two specimens only are known; the holotype from locality 6 and a hypotype from locality 8b.

Superfamily BELLEROPHONTACEA

Family BELLEROPHONTIDAE

Genus *Bellerophon* Montfort, 1808

GENOTYPE, by original designation, *Bellerophon vasulites* Montfort 1808,—"Einfacher Nautilite von Eifel" of Von Hüpsch (1781, pp. 27-28, pl. 3, fig. 22)

The specimen shown by Von Hüpsch as Figure 22 on Plate 3, present whereabouts unknown, is here designated as the lectotype of *Bellerophon vasulites* Montfort. This selection will be discussed at another time, but advantage is taken of this opportunity for recording it.

Bellerophon sp.

(Plate 4, figure 2)

A very small species of the genus with an evenly rounded dorsum, fasciculated lines of growth, and a rather narrow sinus in the anterior lip which culminates in the middle of the lip in a slit about one-quarter of a whorl in depth. The only specimen was probably about 3 mm. in diameter when unbroken.

DISCUSSION: This form is represented by only the external mold of a part of the anterior lip. The mold is good and yields sharp squeezes, but too small a fragment of the shell is represented to warrant naming the species. Yet it seems worth while to record the occurrence of the genus *Bellerophon* in the Whitehorse formation because the genus is known with certainty only in the Paleozoic where, however, it has a long range.

OCCURRENCE: Locality 8a.

Superfamily PLEUROTOMARIACEA

Family PLEUROTOMARIIDAE

Subfamily GOSSELETININAE

Genus *Baylea* de Koninck, 1883

GENOTYPE, by original designation, *Trochus yvanii* Leveille.

The name *Yvania* Fischer, 1885, was proposed to replace *Baylea* de Koninck on the erroneous supposition that it was a homonym of *Bayleia* Munier-Chalmas, 1873. The two names are indeed similar and have the same derivation but they are different in termination and may not under the Rules be emended to conflict with one another.

Baylea capertoni (Beede)

(Plate 4, figures 3 a-i)

Pleurotomaria capertoni BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 163, pl. 8, figs. 9, 9a, 9b.

Pleurotomaria agnostica BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 164, pl. 8, figs. 13a, 13b.

Small, subturbinate gastropods with about 13 rather sharp, elevated revolving lirae, with a selenizone just above the third lira below the upper suture, this lira forming the periphery of the shell; whorl profile rather strongly rounded; sutures deep; nucleus seemingly composed of about 1½ smooth whorls, the ephebic ornamentation and selenizone being present on the third whorl; base rounded, seemingly narrowly phaneromphalous; columellar lip not well known but seemingly reflexed about the narrow umbilicus; parietal lip unknown; outer lip with a rather shallow and inconspicuous sinus culminating in the groove between the second and third revolving lirae below the upper suture and just above the periphery in a probably short, notch-like slit (not actually observed) that gives rise to a selenizone, the margin of the lip (as outlined by growth lines) leaving the upper suture with gentle backward obliquity and passing to the upper bordering lira of the selenizone with slight forward convexity, below the selenizone passing downward and across the base with very slight backward obliquity and forward convexity; selenizone concave between its bordering lirae with fine, sharp lunulae gently concave forward and with a very faint median revolving lira in some specimens; revolving ornamentation 13 to 15 revolving lirae which may be divided into three categories: (1) Four relatively strong lirae, two above the periphery, one forming the periphery, and the

fourth falling rather low on the side between a relatively wide lateral groove and the lirae of the second category below, (2) nine lirae on the base below the last mentioned of the previous category and the umbilicus, and (3) two very fine lirae only developed on some specimens arising by intercalation, one on the selenizone between

TABLE 5.—*Distribution of gastropod specimens*

Showing number of specimens found at various localities. The numbered localities are those shown on pages 278-280.

	No. 1	No. 4	No. 6	No. 7a	No. 7d	No. 8a	No. 8b	No. 9	Exact Locality Unknown	Totals
Lepetopsis? haworthi (Beede)			1				1			2
Bellerophon sp.						1				1
Baylea capertoni (Beede)	4	2	3	1	4	3	1	2	1	21
Worthenia beedei n. sp.								1		1
Murchisonia gouldii		42	4	19	9	3	5	10	16	108
Taosia dozierensis (Beede)			1	1				1	2	5
Cyclites depressus (Beede)	1									1
Naticopsis transversus (Beede)	4	1	1	5	2	2		2	3	20
Girtyspira? alvaensis (Beede)	1									1
Streptacis permiana (Beede)			2	2	1	1			1	7
Cyclobathmus haworthi (Beede)	3			2	1	4	1		4	15
Plagioglypta girtyi n. sp.				1			1			2
										184

the second and third lirae of the first category, and the other in the relatively wide lateral interspace; transverse ornamentation many very fine, sharp, even and regular, closely spaced growth lines; shell structure unknown. The holotype, a specimen of about six whorls, measures about 6 mm. in height, about 4 mm. in width, and has a pleural angle of 45 degrees. The sides of the spire are somewhat convex, and younger specimens show a wider pleural angle up to about 80 degrees.

DISCUSSION: Although the revolving ornamentation on this species is somewhat more strongly developed than common in the genus, this species is referred to *Baylea* because of the form, the position of the selenizone, and the type of the ornamentation. Only the possession of this selenizone serves to bar it from the genus *Yunnania* as now understood. The genus *Baylea* has hitherto been identified only from rocks of Lower and Upper Carboniferous age but will probably be found to be equally characteristic of the Permian. It is not known in the Triassic.

B. capertoni is also very similar to *Pleurotomaria pseudostrigillata* Girty, 1908, and differs from it chiefly in that it lacks the row of elongated nodes just below the upper suture in that species.

Pleurotomaria agnostica Beede is founded on two steinkerns which appear to be identical with steinkerns of *B. capertoni*, the supposed differences being due to poor state of preservation. Hence the name is referred to synonymy.

Beede's comparison of his species with *"Wortheniopsis" kyschertinaeformis* Jakowlew, 1899, may well be pertinent as that species is rather similar and may even be

referable to *Baylea*. The comparison with *"Turbo" helicinus* (Schlotheim) is not apt. There are no Triassic forms with which it may be compared, unless it is with various species of the genus *Euryalox* Cossmann, 1897, with which, however, the resemblance is entirely superficial.

Side-by-side comparisons have been made between specimens of this species including the holotype and the type of *Pleurotomaria texana* Girty (1908) which it resembles very closely. It differs principally in being somewhat smaller and more delicate. The general shape of the two shells is similar, though Beede's species is perhaps a little more slender when mature. Except that they are not so coarse, the revolving lirae of Beede's species match those of Girty's species in every detail, including on some specimens the very fine lira in the wide space on the side below the periphery. This wide space Girty was inclined to regard as the position of the selenizone, as indeed was Beede. The selenizone of *B. capertoni*, however, is definitely not at this position but in the groove next above. The writer has had the privilege of studying the holotype of *P. texana* and can see on it no direct evidence of the position of the selenizone. He is inclined to place it in the groove above that in which Girty placed it principally because of the close similarity of all other features with those of *B. capertoni* which suggests the homology of this feature also.

OCCURRENCE: Fairly common at many localities. Four specimens in Beede's collection are from locality 1 and three from locality 6. The other collections show two specimens from locality 4, one from locality 7a, four from locality 7d, three from locality 8a, one from locality 8b, two from locality 9, and one specimen not clearly labeled for locality.

Subfamily LOPHOSPIRINAE

Genus *Worthenia* de Konick, 1883

GENOTYPE, by original designation, *Turbo tabulatus* Conrad, 1835

Worthenia beedei Knight, new species

(Plate 8, figure 2)

DESCRIPTION: Small gastropods with a rather high, turreted spire, with a fine revolving ornamentation, and an angularly convex, crenulated selenizone forming the angulated shoulder of the whorl; whorl profile strongly and sharply shouldered, the upper surface sloping outward and downward from the upper suture to the point of the shoulder at an angle of about 45 degrees with the vertical, below the point of angulation passing downward and inward at an angle of about 22 degrees with the vertical; sutures shallow; nucleus unknown; base unknown; columellar and parietal lips unknown; outer lip with a broad, shallow sinus culminating at the point of the shoulder seemingly in a slit of unknown depth which gives rise to a selenizone, the margins of the lip (as shown by growth lines) passing downward from the upper suture to the selenizone with gentle backward obliquity and very slight forward convexity, below the selenizone passing downward at first with forward obliquity which turns promptly to a gentle backward obliquity; selenizone with a sharp angulation which forms the point of the shoulder, lunulae fine and regular forming crenulations, gently concave forward; a pair of relatively strong fine revolving lirae just below the upper suture followed by four or five much finer ones before the selenizone is reached, five or six very fine ones on the inward sloping upper part of the outer whorl face below the selenizone followed by a single relatively

strong lira and then two or three finer ones before the lower suture is reached, the ornamentation on the base unknown; shell structure unknown. The holotype must have measured something like 10 mm. in height when unbroken with a width of about 5 mm. and a pleural angle of about 35 degrees, all figures rough approximations.

Discussion: This species is described and named for, even though it is based on an external mold showing only the spire, its generic assignment is certain, and the details of the spire are so well preserved that there should be no trouble in recognizing it.

The genus *Worthenia* as now understood ranges at least from the Lower Carboniferous through the Permian and, if certain European workers are to be credited, throughout the Triassic. The genus then, as now known, has too great a range in time to be very significant although it may be said that this species resembles *Worthenia* of the Upper Carboniferous rather than those species of the Triassic referred to the genus.

Occurrence: Only a single specimen is known and that from locality 9.

Subfamily Murchisoniinae

Genus *Murchisonia* d'Archiac and de Verneuil, 1841

Genotype, by subsequent designation of Woodward, 1856, *Murchisonia bilineata* (Goldfuss MS., von Dechen), 1832, = *Muricites turbinatus* Schlotheim, 1820.

Murchisonia gouldii Beede

(Plate 5, figures 1-14; Plate 6, figures 1 a-e)

Murchisonia gouldii Beede, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 167, pl. 8, figs. 6, 6a, 6b.

Murchisonia collingsworthensis Beede, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 166, pl. 8, figs. 7, 7a.

Orthonema? texana Beede, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 168, pl. 8, figs. 5, 5a.

Description: High-spired gastropods of 10 or 12 whorls when mature, with a wide shallow sinus in the outer lip culminating on a rounded carina in a seemingly short slit that gives rise to a selenizone and with two rather strong, closely spaced revolving costae at the line of the lower suture; whorl profile gently to rather strongly shouldered just below the upper suture, very gently concave between the subsutural shoulder and the rounded, selenizone-bearing carina and very gently to rather strongly concave between the carina and the two revolving costae at the lower line of suture; the selenizone-bearing carina varying markedly in its position on the outer whorl face from about mid-whorl to very low on the whorl, and the relative width and the profile of the bands above and below it varying accordingly; sutures sharply incised, but not very deep; nucleus not well known but the neanic whorls very much more sharply angulated than the ephebic; base rather flatly rounded or even slightly concave, anomphalous; columellar lip very slightly thickened and reflected; parietal inductura very thin or wanting; outer lip with a broad, shallow sinus culminating on the carina in a seemingly short slit about one tenth the whorl circumference in depth, the slit giving rise to a selenizone, the margin of the lip as shown by lines of growth passing from the upper suture to the selenizone with moderate backward obliquity and slight forward convexity, below the selenizone passing onto the base with mod-

erately strong forward obliquity and turning on the base with fairly strong forward convexity to a moderate backward obliquity at the columella; selenizone at the crest of the carina bordered by two obscure lirae, very slightly convex, in some specimens with very fine and obscure revolving lirae, the lunulae very gently concave forward, commonly faint and irregular but in some specimens fasciculated to form regular crenulations; ornamentation other than the foregoing very fine revolving lirae above the selenizone which fail of expression on many specimens and three or four often more strongly developed lirae on the base, close to the columella, and fine transverse lines of growth; shell unknown. A large specimen of about 12 whorls measures about 18 mm. in height, about 6½ mm. in width and has a pleural angle of about 20 degrees. The pleural angle, like other features of this variable species, varies with a range of from 14 to 30 degrees.

Discussion: That one should throw together under one specific name specimens so different at first glance as the types of *M. gouldii* Beede and *Orthonema? texana* Beede calls for an explanation. That *M. collingsworthensis* Beede is regarded as conspecific with *M. gouldii* calls for less comment. Indeed, although Beede's descriptions are so drawn as to make the latter two seem quite different, a study of the types shows that the only differences are the faint revolving lirae on the lectotype of *M. gouldii* (Pl. 5, fig. 2) not present on the holotype of *M. collingsworthensis* (Pl. 6, fig. 1a), and the slightly greater pleural angle of the latter. A large suite of specimens shows that both these features are quite variable in the species and that the two supposedly distinct forms cannot be separated on the basis of either character.

In respect to *O.? texana* which was referred to a wholly unrelated genus by Beede, though with a query, the case is different, for the resemblance between the type specimens is much less. Beede failed to distinguish the selenizone on the lectotype of *O.? texana* (Pl. 5, fig. 14) which, although not well preserved, can be seen with a considerable degree of assurance. That the species did actually have a selenizone is amply confirmed by an examination of numerous other specimens now at hand that match the lectotype in all particulars. (See Plate 5, figure 12, for example.) Thus we may dispense with this, the supposed generic difference, immediately. Finding that the two supposed species are congeneric, it becomes profitable to compare them more closely. Each has the slight shoulder below the upper suture, each has the selenizone at the crest of a rounded carina, each has the same type of paired revolving costae at the lower line of suture and the somewhat finer costae or lirae close to the columella, each has the moderately flat to concave base; furthermore a study of additional specimens shows that each is variable in respect to the development of fine revolving lirae on the upper half of the whorl. Where the types and the selected associated specimens of the two do differ markedly is in the position of the selenizone-bearing carina. It is proposed to show that in a large collection all intergradations may be found in respect to this feature so that this distinction too fails us, and *O.? texana* must be united with *M. gouldii* and *M. collingsworthensis* under a single name.

In the preliminary sorting out of about 100 specimens no difficulty was experienced in separating the specimens into two lots—*"M. gouldii"* and *"M. texana."* It was only when the careful study of first one lot and then the other was commenced that it was found that the facile preliminary separation was incomplete. Some specimens clearly went one way, and some others just as clearly the other way, but there remained the great bulk of the specimens that were indeterminable. Next there

were sorted out of the combined lots all the specimens (or rather squeezes of specimens, for since all of the significant specimens are external molds the study is based on squeezes) whose preservation was sharp enough to make careful measurements, 14 in number including the lectotypes of *M. gouldii* and *O.? texana*. By measure-

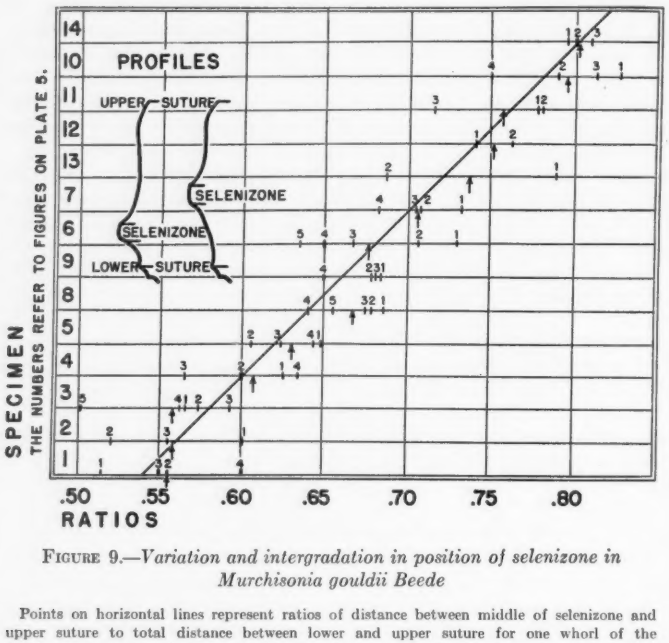

FIGURE 9.—*Variation and intergradation in position of selenizone in Murchisonia gouldii Beede*

Points on horizontal lines represent ratios of distance between middle of selenizone and upper suture to total distance between lower and upper suture for one whorl of the specimen. Arrows mark the mean for the whorls measured. Numbers above the points refer to the whorls of the specimen, number 1 indicating the latest (largest) whorl measured on the specimen concerned, and subsequent numbers the succeeding whorls. Specimens arranged in order of increasing ratios.

Profiles in upper left of figure represent diagrammatic profiles of the whorls of the two extremes. The one on the left represents a specimen with a ratio of 0.80; the one on the right a specimen with a ratio of 0.55.

ments performed with the micrometer eyepiece of the microscope the ratio of the distance from the midline of the selenizone to the upper suture to the total distance from lower to upper suture was determined for each whorl of these 14 specimens well enough preserved to measure—a total of 52 measurable whorls. Each measurement constitutes a numerical expression of the position of the selenizone on the outer whorl face, and it was in respect to this, and features contingent on this, that the only differences between the selected specimens of "*M. gouldii*" and "*M. texana*" could be found. After the difficulties encountered in making a clean assortment of the two supposed forms, it was not surprising to find intergradation from one extreme to the other, an intergradation remarkably complete even when one considers the few

specimens available. The lowest ratio for an individual whorl was 51.4; the lowest mean ratio for all the measured whorls on one specimen—the same specimen—was 55.5. The lectotype of *M. gouldii* gave a low of 52, a mean of 55.8. The highest ratio of a single whorl was 82.6, the specimen giving a mean ratio of 79.5. The lectotype of *O.? texana* gave a mean of 80.1. The difference between these two ratios is a measure of the only considerable difference between the types of *M. gouldii* and *O.? texana,* and this difference is shown diagrammatically in the upper left hand part of text Figure 9, where sketches of two whorl profiles show the extremes. The intergradation is shown diagrammatically in the body of Figure 9 where against co-ordinates are plotted the ratios found on each measured whorl of each specimen arranged in the order of increasing mean ratios. A line connecting the plotted mean ratios is not an ideally smooth curve, but the measurable specimens were few, and such a curve is not to be expected with few specimens. The fact of intergradation seems, however, to be well established and with the lectotype of *O.? texana* at one extreme and the type of *M. gouldii* close to the other. Other measurements taken at the same time show a very imperfect correlation between these figures and the ratio of height to width of the whorls, the latter tending to increase slightly with the other but with some marked exceptions. A more marked tendency is for the pleural angle to decrease as the selenizone moves downward on the whorl face, but even this is irregular, and there are some examples very markedly the other way. There seems to be little correlation between these ratios and the degree of expression of the revolving ornamentation. In the specimens at hand some of those with intermediate ratios have the most strongly expressed revolving ornamentation.

An interesting feature of this species is the highly angular early whorls. In some juvenile specimens at least, particularly those with slender form and relatively low selenizone, the selenizone is placed somewhat on the under side of the carina which at this stage is quite sharp, and such specimens would fit perfectly into the genus *Goniasma* Tomlin, 1930, with which the double costae at the line of the lower suture are also in harmony. And yet at adult stages there appear to be no grounds on which to separate the species from *Murchisonia.* To compare *Murchisonia gouldii* with other murchisonids hardly seems profitable, although the similarity of this with the five or six species described by Jakowlew in 1899 from the Donetz basin in Russia is striking. Can it be that Jakowlew was also dealing with a highly variable species rather than with several distinct ones?

Occurrence: This highly variable species occurs more abundantly and at more localities than any other. Beede's collection contained four specimens from locality 6. In the other collections there are 42 specimens from locality 4, 19 from locality 7a, 9 from 7d, 3 from 8a, 5 from 8b, 10 from 9, and 16 specimens not clearly labelled for locality. This makes a total of 108 specimens, more than five times the number of specimens of any other gastropod species.

After the above study was completed a specimen of a gastropod collected by Mr. John M. Hills from a core from the Amerada No. 2 Leek Well in Sec. 3, Block 74, Winkler County, Texas, was submitted for identification. It proved to be a typical example of this species tending toward the end of the series with higher whorl ratios. The specimen came from a depth of 3117 feet and from a horizon thought to be the Capitan limestone in its reef facies.

Genus *Taosia* Girty, 1939

Genotype, by original designation, *Murchisonia copei* White, 1881.

Taosia dozierensis (Beede)

(Plate 9, figures 1 a-d)

Orthonema dozierense Beede, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 168, pl. 8, fig. 8.

Description: Small, high-spired, many-whorled gastropods with nearly flat outer whorl, faces bounded below by an obscure angulation, with faint transverse undulation especially on the earlier whorls and seemingly with a selenizone somewhat above the middle of the whorl face; whorl profile almost flat and sloping gently outward in conformity with the sides of the spire, a slightly keeled angulation between the whorl face and the base, the angulation falling just above the lower suture; sutures shallow but sharply incised below the aforementioned angulation; nucleus unknown; base conical, anomphalous; columellar lip seemingly slightly reflexed; parietal inductura thin or wanting; outer lip with a broad, very shallow sinus that culminates somewhat above the middle of the whorl probably in a notch or slit of unknown depth that seemingly gives rise to a selenizone, the actual course of the lip insufficiently known for detailed description; selenizone seemingly of moderate breadth, and nearly flat, its details not well known; known ornamentation other than features enumerated above broad and rather obscure transverse undulations, better developed on the earlier whorls; shell unknown. The largest specimen at hand, one that must have had about 12 whorls, must have measured above 18 mm. in height before breakage, with a width of about 4 mm. and a pleural angle of about 12 degrees. The holotype, a specimen of about 7½ mm. in height, has a pleural angle of about 17 degrees.

Discussion: Of five fairly good specimens of the species studied, all of them, including the holotype, are external molds. These molds are fairly sharp but they are not sharp enough to show as clearly as one would like on squeezes what appears to be a selenizone slightly above the middle of the whorls and so nearly flush with the surface and so little set off as to be almost indistinguishable. The growth lines on none of the specimens are clearly shown, but on several there are faint suggestions of them, and they seem to bend obliquely forward below the supposed selenizone, thus tending to confirm the presence of the sinus, notch or slit, and selenizone tentatively described. Of course, the validity of the reference of the species to *Taosia* depends on the correctness of the interpretation of the specimens as having these characters. The general form of the shell and particularly the angulation passing around the whorls just above the sharply incised but shallow lower suture conform strictly with similar characters in the genotype of *Taosia*. If these characters have been misunderstood it is possible that Beede's original reference of the species to *Orthonema* is correct.

No significant species is known to the writer with which this can be compared. *Taosia copei* (White), the genotype, is a much larger form without the transverse undulations of this one. It is from the Magdalena formation of Pennsylvanian age.

Occurrence: Only five specimens of this species are known. There is one in the Beede collection from locality 6. In the other collections there is one specimen from locality 7a, one from locality 9, and two specimens without adequate locality labels.

Superfamily Trochonematacea

Family Cyclonematidae

Genus *Cyclites* Knight, new genus

Genotype, *Pleurotomaria multilineata* Girty, 1908. This species is designated as genotype rather than *Worthenopsis? depressa* Beede even though the writer believes them to be identical because the type of the former shows more details of the characters of the genus than does the type of the latter.

DIAGNOSIS: Small, rather low-spired, minutely phaneromphalous gastropods with revolving ornamentation and with subangularly shouldered whorls and an outer lip that is straight and gently oblique backwards below the angulation and believed to be so above it.

While the entire course of the extremely important apertural margin is unknown yet that part of the margin that is known taken in connection with the other characters seems to be sufficient to characterize the genus. The straight and gently oblique character of the outer lip on the sides of the whorl below the angulation is such that commonly correlates with a similar character on the upper whorl face so that we may be reasonably sure of even the outer lip until better specimens can be found.

The genus, as here conceived, differs principally from *Cyclobathmus*, new genus, and from such superficially similar genera as *Tretospira* Koken, 1892, and *Worthenippis* Böhm, 1895, the two latter of Triassic age, in the form of both known and inferred portions of the outer lip. In *Cyclobathmus* the lip is concave forward above the angulation and convex forward below. *Cyclobathmus* is also relatively high spired and is anomphalous. *Tretospira* has a distinct sinus and notch in the outer lip at the angulation, and *Wortheniopsis* has a slit and selenizone. *Plocostoma* Gemellaro, 1899, is also superficially similar but has a selenizone and a toothed columellar lip.

Cyclites depressus (Beede)

(Plate 8, figures 1 a-e)

Worthenopsis? depressa BEEDE, Kansas Univ. Bull., vol. 4 (1907) p. 164, pl. 8, figures 4, 4a.

Pleurotomaria multilineata GIRTY, U. S. Geological Survey Prof. Paper 58 (1908) p. 468, pl. 23, figs. 25 to 25d.

DESCRIPTION: Small, relatively low-spired, subtrochiform gastropods with many fine revolving lirae and seemingly without sinus or slit in the outer lip; whorl profile with a rather wide, moderately arched subhorizontal area above a gently subangular shoulder, a rather narrow, slightly flattened outer whorl face and a gently rounded base; sutures unknown; nucleus unknown; base rounded, narrowly phaneromphalous; columellar lip thin, reflected about the narrow umbilicus; parietal inductura thin; outer lip below the subangular shoulder straight and with a gentle backward obliquity, its course above the shoulder unknown but probably similar to that above; ornamentation numerous revolving lirae imperfectly known above the angulation of the whorl but seemingly about eight in number, below the angulation on the narrow outer whorl face two rather widely spaced lirae followed below on the base by about twenty fine lirae that become finer and more closely spaced as the umbilicus is approached, shell structure unknown. The holotype has a height of approximately 6 mm., a width of about 8½ mm., and a pleural angle of about 125 degrees.

DISCUSSION: The above description is based on a study of the holotype, a rather rough steinkern, and on the holotype of *Pleurotomaria multilineata* Girty, a name here referred to synonymy, which consists of a steinkern and a sharp external mold of part of the lower part of the shell. Doctor Girty was not only kind enough to put the type of his species at the writer's disposal but also made a side-by-side comparison of the types of both. He agreed with the writer that the forms are conspecific and his name must go into synonymy.

OCCURRENCE: Beede's holotype, from locality 1, is the only specimen in the Whitehorse collections. Girty's specimen (*P. multilineata*) is said to have come from the lower part of the Middle Delaware Mountain formation at the southern end of the

Guadalupe Mountains. This is some 800 feet below the Capitan limestone at that locality.

Superfamily NERITACEA

Family NERITOPSIDAE

Subfamily NATICOPSINAE

Genus *Naticopsis* M'Coy, 1844

GENOTYPE, By subsequent designation of Meek and Worthen, 1866, *Naticopsis philipsii* M'Coy, 1844.

Naticopsis transversus (Beede)

(Plate 7, figures 1-7; Plate 6, figures 3 a-c)

Naticella transversa BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 171, pl. 8, figs. 1, 1a.

Strophostylus permianus BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 170, pl. 8, figs. 2-2c.

DESCRIPTION: Rather small, subglobular naticiform gastropods with the inner lip flattened and somewhat extended in the plane of the aperture and with fine lines of growth which in some specimens are fasciculated on the earlier whorls to form rather striking transverse costae; whorl profile moderately rounded between sutures, strongly rounded on the final whorl; sutures moderately deep; nucleus unknown; base rounded, anomphalous; columellar and parietal lips continuous and together forming a plate-like inner lip flattened and extended in the plane of the aperture; outer lip thin, without a sinus, its margin, as shown by the growth lines, leaving the upper suture in an almost radial direction but turning rather quickly with forward convexity to a moderate backward obliquity which continues across the base; ornamentation fine lines of growth which on some specimens, especially at the earlier stages of growth, are fasciculated to form more or less striking transverse costae; shell itself unknown. A large, perfect specimen must have measured about 9 mm. in height with a width of about the same figure and a pleural angle of something like 110 degrees.

DISCUSSION: Beede's holotype of this species, an excellent external mold in three parts, is at hand. Two of his syntypes of *"Strophostylus permianus"* Beede and 15 or 20 other specimens from the same horizon as the others are also at hand. It is interesting to note on a number of specimens which at adult stages are typical examples of *"Strophostylus permianus"* that the earlier whorls are quite as typically *"Naticella transversa"* with more or less strongly developed transverse costae. Since the development of such costae on *"Naticella transversa"* is the only character that might have distinguished the two supposedly distinct forms and since this character is clearly only the maximum expression of the tendency of the growth lines to fasciculate at earlier stages of growth manifest in varying degrees in many specimens of a single species the writer is here adopting the name *transversa* and placing the name *permianus* in synonymy.

That the *"Naticella transversa"* stage of this species suggests strongly the several species of *Naticella* Münster (not *Naticella* Grataloup) that occur in the Alpine Triassic is undeniable and of little significance, since the same stage also resembles very closely *Naticella americana* Girty, 1915, from well down in the Upper Carboniferous which the writer referred in 1933 to the genus *Natiria* de Koninck. The adult stages of the present species point clearly to *Naticopsis* in the broad sense, and it is to that genus with a long range from the middle of the Paleozoic into the Triassic that the writer refers it.

OCCURRENCE: This is one of the more abundant gastropods in the collections. Beede's collection contains two specimens from locality 1 and one from locality 6. The other collections contain two specimens from locality 1, one from locality 4, five from locality 7a, two from 7d, two from 8a, two from 9, and 3 specimens not labelled for locality.

Superfamily SUBULITACEA

Family PSEUDOMELANIIDAE

Genus *Girtyspira* Knight, 1936

GENOTYPE, by original designation, *Bulimella canaliculata* Hall, 1858.

Girtyspira? alvaensis (Beede)

(Plate 8, figure 3)

Bulimorpha? alvaensis BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) p. 169, pl. 8, fig. 11.

DESCRIPTION: Moderately high-spired gastropods of moderate size; whorl profile gently arched, possible (though not probably) slightly shouldered close to the upper suture; sutures seemingly shallow; nucleus unknown; base rounded, narrow, anomphalous; columellar lip seemingly without folds or channels; parietal lip unknown; outer lip unknown; ornamentation unknown; shell unknown. The holotype must have measured about 15 mm. in height when entire and 7 or 8 mm. in width.

DISCUSSION: This species is represented in the collections by one specimen, Beede's holotype. That specimen is a steinkern so poorly preserved that it is impossible to recognize even its genus with any certainty. The writer takes this opportunity to protest the formal description and naming of gastropod species based on such very inadequate material. In doing this he is not criticizing Doctor Beede. In his zeal to be of service he is only doing what so many do, many to the most absurd extent. To base named species on material of this sort is of no service to the stratigrapher and is a nuisance to the systematist. The most that should be done is to figure a specimen—without basing a species on it—and the value of even this is open to question.

OCCURRENCE: The only specimen is from locality 1.

Superfamily LOXONEMATACEA

Family STREPTACIDIDAE

Genus *Streptacis* Meek, 1872

GENOTYPE, by monotype, *Streptacis whitfieldi* Meek, 1872.

Streptacis permiana (Beede)

(Plate 9, figures 2 a-c)

Loxonema permiana BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 167, pl. 8, figs. 14, 14a.

DESCRIPTION: Very small, slender, high-spired, many-whorled gastropods with a sinus in the outer lip; whorl profile moderately arched between sutures; sutures shallow; nucleus unknown; base rounded, anomphalous; columellar lip rather strongly arcuate; parietal inductura seemingly thin or wanting; outer lip with a well-marked sinus culminating roundly rather high on the whorl face, the margin of the lip, as shown by growth lines, leaving the upper suture with seemingly forward convexity onto the base and turns suddenly backward close to the columellar lip; ornamentation,

other than fine lines of growth, lacking; shell unknown. The largest specimen measures about 7 mm. in height, 2.1 mm. in width, and has a pleural angle of about 20 degrees.

Discussion: Seven specimens of this species are at hand, including Beede's holotype. They are all rather sharp external molds making squeezes on at least two of which growth lines are visible. No specimen preserves the nucleus on which a conclusive recognition of the genus *Streptacis* must rest, but the form of the outer lip with its rounded sinus culminating high on the whorl face is thought to be sufficient for the ordinary recognition of the genus.

To compare a highly generalized form like this one with others for the sake of stratigraphic correlations is futile. It has at least a superficial resemblance—and the superficial characters are the only ones known in most cases—to many species ranging throughout geologic time. Other described species of the genus *Streptacis* are all from the Upper Carboniferous.

Occurrence: Beede's collection contains two specimens from locality 6. The other collections contain two specimens from locality 7a, one from locality 7d, one from 8a, and one specimen without adequate locality label.

Order MESOGASTROPODA

Superfamily Littorinacea

Family Purpurinidae

Genus *Cyclobathmus* Knight, new genus

(Gr. Κύκλος—circle; Βαθμος—a stair)

Genotype, *Trepospira haworthi* Beede, 1907.

Diagnosis: Small anomphalous gastropods with revolving ornamentation, with angularly shouldered whorls, and an outer lip that is very gently concave forward above the angulation and very gently convex forward below, the two divisions continuous across the angulation without a sinus or slit and with very gentle forward obliquity only.

The genus is not closely similar to any in the Paleozoic known to the writer. *Plocostoma* Gemmellaro, 1889, from the Permian has a slit and selenizone on the outer face of the analogous angulation and a toothed columellar lip. *Tretospira* Koken, 1892, of the Triassic has a distinct sinus and notch at the analogous angulation, and *Wortheniopsis* Böhm, 1895, also Triassic, has a slit and selenizone at the same position.

Cyclobathmus haworthi (Beede)

(Plate 9, figures 3 a-f)

Trepospira haworthi Beede, Kansas Univ. Sci. Bull., vol. 4 (1907), p. 166, pl. 8, figs. 3-3b.

Description: Small, moderately high spired gastropods with an angularly shouldered whorl, with fine revolving ornamentation, and an outer lip without sinus or slit; whorl profile flattened above, sloping outward and downward from the upper suture at an angle of about 45 degrees to a rather sharp angulation below which it passes downward and slightly inward as it turns gradually onto the base; sutures not deep; nucleus not adequately known but seemingly with rounded whorls and a rather high spire; base gently convex-conical, anomphalous; columellar lip somewhat thickened, reflexed; parietal inductura thin; outer lip as indicated by lines of growth, leaving

the upper suture with a very slight forward obliquity and, crossing the upper whorl face with very gentle forward concavity, passing across the angulation without deflection onto the outer whorl face where it turns gradually with gentle forward convexity to a very gently backward obliquity on the base; ornamentation rather fine rounded, revolving lirae, the strongest and sharpest of which forms a low carina on the angulation of the whorl, from 4 to 8 of the lirae above the angulation and 10 to 18 below it, the number increasing by intercalation as the shell grows, and very faint transverse growth lines; shell seemingly thin, its structure unknown. The holotype must have measured a little over 5 mm. in height before breakage with a width of 3 mm. and a pleural angle of about 48 degrees.

DISCUSSION: The holotype and two paratypes at hand are fairly good steinkerns and serve to fix the species. There also are several quite sharp external molds from the same horizon, definitely of the same species, and squeezes from the molds show clearly the external features.

Pleurotomaria delawarensis Girty, 1908, resembles this species in its small size and general form. It is, however, clearly distinguished by the presence of two rather strong revolving keels on the outer whorl face below the carinate shoulder. Girty's species may possibly belong to this genus, but since the form of the outer lip is unknown to the writer, it is not here referred. No other form with which *C. haworthi* can be profitably compared is known to the writer unless *Tretospira dives-ouralica* Jakowlew, 1899, a larger, more robust and lower-spired species from the Permian of the Donetz Basin, which may well be referable to *Cyclobathmus*. *Rissoa obtusa* Brown as figured by King, 1850, and *Turbo permianus* King, 1850, are perhaps also members of the genus.

The writer often wondered why Beede referred this species to so unlikely a genus as *Trepospira* Ulrich. It seems probable that he simply wrote *"Trepospira"* in error for *Tretospira* Koken, a genus which superficially resembles *Cyclobathmus*.

OCCURRENCE: Beede's collection contains three specimens all from locality 1. The other collections have two specimens from locality 7a, one from locality 7d, four from locality 8a, one from locality 8b, and four not adequately labelled as to locality.

Class SCAPHOPODA

Family DENTALIIDAE

Genus *Plagioglypta* Pilsbry, 1898.

Plagioglypta girtyi Knight, new species

(Plate 6, figure 2)

DESCRIPTION: Small, nearly straight, slender, rod-like shells tapering very gradually with numerous fine annular lirae. The fragment of the holotype and largest specimen measures about 14 mm. in length, and in this distance the diameter at the apertural end whose mold is preserved is reduced from about 1½ to 1¼ mm. The annular lirae number about 6 to the millimeter at the smaller end and about 10 to the millimeter at the apertural end.

DISCUSSION: The holotype and paratype are sharp external molds that yield excellent squeezes.

This species compares most closely with *P. annulistriata* (Meek and Worthen) from the middle of the Upper Carboniferous but is almost if not quite straight, instead of being curved, and apparently has more regular lirae.

OCCURRENCE: One specimen was derived from locality 7a and one from locality 8b.

BRACHIOPODS OF THE WHITEHORSE SANDSTONE

BY KENNETH G. BRILL, JR.

Family TEREBRATULIDAE

Genus *Dielasma* King

Dielasma schucherti Beede

(Plate 10, figures 1-4)

Dielasma schucherti BEEDE, Oklahoma Geol. Survey, 1st Bienn. Rept., Advance Bull. (1902) p. 7, pl. 1, figs. 1-1c.
Dielasma schucherti BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) No. 3, p. 148, pl. 5, figs. 1b, 1c, 1d, 1f, 1m (not figs. 1, 1a, 1g-l).

DESCRIPTION: Shell biconvex, subpentagonal in outline; valves biplicate in adults; greatest width near midlength, narrowing rather abruptly to the beak and contracting gradually to the slightly rounded or straight anterior margin, which is cuneate in longitudinal profile. Specimens at hand are preserved as internal molds, but shell fragments show that punctae are arranged in quincunx; surface smooth except for lines of growth. Ventral valve convex, greatest convexity at the umbo; sulcus bears a rounded median fold which becomes obsolete in the flattened surface of the valve at midlength; narrow sulci on both sides of the median fold angular in cross section; anterior margin of the shell decidedly biplicate; in some internal molds two low rounded ridges arise on each side of the median line of the umbo and extend anteriorly parallel to the dental lamellae and become obsolete near the midlength, probably pallial sinuses in the actual shell. Dorsal valve more convex, greatest convexity transverse to length; anterior to midlength the fold is split into a rounded median sulcus and two lateral angular folds, corresponding to the configuration of the opposite valve; internally, the hinge plate joins inner surface of valve along its median line, and median septum rises at the junction and extends anteriorly about one-third the length of the valve; relation of the hinge plate to the dental sockets is not known; muscle impressions present on hinge plate; brachidia not observed.

Dimensions of types of Dielasma schucherti

	Length (mm.)	Width (mm.)	Thickness (mm.)
Neotype (Kans. Univ. 21,601)	13.8	10	8.2
Hypotype 1 (Peabody 15,276)	15.5	12	7.5
Hypotype 2 (Peabody 15,277)	13.5	10	6.3

DISCUSSION: The holotype and other specimens of this species described by Beede in 1902 were destroyed by fire. He redescribed (Beede, 1907, p. 142) *Dielasma schucherti* stating that

"In order that there might be specimens for comparison as near the types as possible I have figured a new set——".

The present writer has re-figured the neotype illustrated by Beede (1907, Figs. 1b-d). This neotype was chosen by Beede because of its similarity to the holotype figured in the 1902 paper. Two hypotypes from Professor Schuchert's collection made at, or near, the type locality at Whitehorse Springs, Oklahoma, are illustrated (Pl. 10, figs. 1, 4).

Beede (1907, Pl. 5, figs. 1, 1a, 1e, 1g-1j) illustrated specimens which he considered to be immature individuals of *Dielasma schucherti*. These appear to be distinct from *Dielasma* and should be included in the genus *Pseudodielasma* described in the pages following.

Figure 1k on Plate 5 in Beede's 1907 paper is a specimen of *Composita mexicana* (Hall). Figure 1l on the same plate illustrates a specimen which belongs to the species *Composita subcircularis* Brill, n. sp.

In its biplicate character *Dielasma schucherti* resembles *D. biplex* Waagen from the Permian of the Salt Range of India. It differs from the latter species, however, in being smaller and having plications which are limited to the anterior half of the shell.

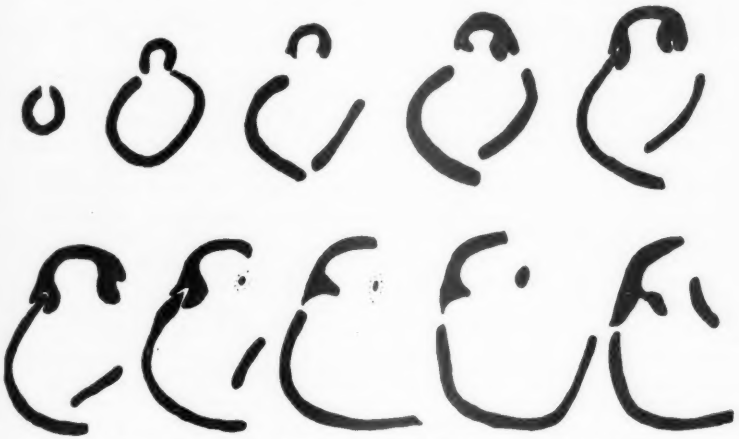

FIGURE 10.—*Serial sections of Pseudodielasma perplexa Brill*

Illustrating the relation of crura to socket plates. Sections cut at slightly less than a right angle to the long axis of the shell, × 10. Paratype, No. 15,279, Peabody Museum, Yale University.

Genus *Pseudodielasma* Brill, n. gen.

GENOTYPE, *Pseudodielasma perplexa* Brill, n. sp.

DESCRIPTION: Shell terebratuliform, smooth, biconvex. Preservation in the present specimens is such that the presence of punctae is indeterminate. The ventral valve may have a fold, and the dorsal valve may have a sulcus. When present the fold and sulcus are not well defined. The ventral beak bears a small circular foramen. Internally dental lamellae are absent. The sockets in the opposite valve are formed by the thickening of the walls of the shell. From the median edge of the socket plates (Fig. 10) the crura extend anteriorly about one-third of the length of the valve. On the ventral side the anterior extremity of each crus is produced slightly to form a small, medially directed jugal process. The dorsal anterior ends of the crura are joined by an anteriorly directed, V-shaped bar (Pl. 10, figs. 10-12). The V-shaped bar shown by Beede (1907, Pl. 5, fig. 1) is not completely fused at the center. According to him this specimen is immature; however, it seems more likely that the specimen is a pathologic one since shell dimensions and size of the loop are the same as those in which the bar is solidly fused. This genus differs from *Dielasma* in the shape of its loop and in the absence of dental lamellae.

Dielasma schucherti var. *minor* King (1930, p. 133) from the upper part of the Word formation of the Glass Mountains in Texas resembles, externally, a miniature

D. schucherti. Topotypes of King's variety from the Yale Peabody Museum collections were sectioned and, although the loops were not preserved, dental lamellae were absent. The absence of dental lamellae and the similarity of form suggest, it seems, that it is congeneric with *Pseudodielasma.*

Pseudodielasma perplexa Brill, n. sp.

(Plate 10, figures 5-12)

Dielasma schucherti Beede, Kansas Univ. Sci. Bull., vol. 4 (1907) no. 3, p. 148, pl. 5, figs. 1, 1a, 1e, 1g-j.

Description: Shell small, smooth, subovate to subpentagonal in outline, biconvex, greatest convexity of each valve in transverse section, greatest width at midlength or slightly anterior thereto. In no specimen is the shell well enough preserved to show presence of punctae. In some specimens there is a fold and sulcus. When present the anterior one-third of the dorsal valve bears a broad flattened fold, and occasionally there is a shallow indistinct sulcus on each side. In the ventral valve the sulcus, if present, is broad and flattened and may bear indistinct lateral folds corresponding to the lateral sulci of the opposite valve. Internally, the deep impressions of the oval-shaped adductor muscle are present on the umbo. Anterior and lateral to these are the more elongate impressions of the diductor muscles. In the interior of the dorsal valve the diductor scars are represented by a small depression near the beak; the elongate adductor impressions lie slightly anterior to the beak.

Dimensions of types of Pseudodielasma perplexa

	Length (mm.)	Width (mm.)	Thickness (mm.)
Holotype (Peabody 15,278)	6.7	5.1	3.8
Paratype 2 (Kans. Univ. 21,602)	7.0	5.4	4.1

Occurrence: Whitehorse sandstone, locality 1 (paratype 2), locality 9 (holotype and paratype 1), and locality 7a.

Family Athyridae

Genus *Composita* Bronn

Composita mexicana (Hall)

(Plate 10, figures 13, 14)

Terebratula mexicana Hall, Emory's Rept. U. S. and Mexican Boundary Survey (1858) vol. 1, pl. 20, fig. 2.
Dielasma schucherti Beede, Kansas Univ. Sci. Bull., vol. 4 (1907) No. 3, pl. 5, fig. 1k.
Composita mexicana (Hall), Girty, U. S. Geol. Survey, Prof. Paper 58 (1908) p. 389-390.
Composita mexicana (Hall), King, Univ. Texas Bull. 3042 (1930) p. 128, pl. 43, figs. 1-11 (for complete synonymy).

Description: Shell small, subpentagonal, biconvex, greatest width slightly anterior to midlength. Ventral valve bears a broad, flattened sulcus which narrows and eventually becomes obsolete in the posterior third of the valve. A spatulate linguiform extension is present on the anterior margin. Ventral beak rather broad, and pedicle foramen circular. Internally, dental lamellae are present. The fold in the dorsal valve is not distinguishable from the convexity of the valve. Internally, a median septum separates the adductor muscle impressions. Internal molds are present in the collections at hand, but fragments of shell indicate the lack of punctae and that the surface was smooth except for growth lines, which become rather coarse near the anterior margin.

DISCUSSION: The present specimens agree fairly well with Hall's original illustration and Girty's subsequent description of the species. In the main, they are somewhat smaller than the type specimen and due to the absence of shell have a less inflated umbo. One specimen is rather close to *C. mexicana* var. *guadalupensis* Girty (1908, p. 390); however, King (1930, p. 128-129) believes Girty's variety is synonymous with the original species.

DIMENSIONS: Figured specimen (Peabody 15, 280), length, 12.7 mm.; width, 10.8 mm.; thickness, 7.2 mm.

OCCURRENCE: Whitehorse sandstone, localities 1, 7a, 9.

Composita subcircularis Brill, n. sp.

(Plate 10, figures 15-18)

Dielasma schucherti BEEDE, Kansas Univ. Sci. Bull., vol. 4 (1907) no. 3, pl. 5, fig. 11.

DESCRIPTION: Shell small, subcircular to subovate, a little longer than wide, greatest width slightly anterior to midlength; surface smooth except for fine lines of growth; ventral valve convex, greatest convexity slightly posterior to middle of valve; surface rises abruptly from the umbo to the point of greatest convexity and descends more gradually to the anterior margin; beak does not project beyond the plane of commissure, being short and expanding rapidly to posterior lateral margins; lateral margins of valve are broadly rounded; there is but slight transverse curvature to the anterior margin where the short, rounded linguiform process is extended into the opposite valve; a broad flattened indistinct mesial sulcus present in the anterior half of the valve; internally, strong dental lamellae are present; narrow, shallow furrow present on each side of the median line, arising between the dental lamellae and diverging slightly laterally toward the anterior third of the valve where it becomes obsolete; dorsal valve convex, greatest convexity in posterior third of valve; a broad flattened fold corresponds to the sulcus of the opposite valve; internally, no median septum has been observed; hinge plate bears the crura which support the spires; saddle-shaped jugum present.

Dimensions of types

	Length (mm.)	Width (mm.)	Thickness (mm.)
Holotype (Kansas Univ. 21,604)	12	11	6.8
Paratype (Kansas Univ. 21,605)	10.3	10	6.2

DISCUSSION: *Composita subcircularis* differs from *C. mexicana*, which occurs in the same beds, in having a less angular outline, less convexity of the shell, and no elongate linguiform extension of the ventral valve. *C. subcircularis* seems to be close to *C. ovata* Mather of the Lower Pennsylvanian but differs in that the Permian species is smaller, develops the fold and sulcus at an earlier stage, and has a less pronounced ventral beak.

OCCURRENCE: Whitehorse sandstone, localities 1, 9.

BRYOZOA OF THE WHITEHORSE SANDSTONE

BY RAYMOND C. MOORE

GENERAL STATEMENT

Seven collections of bryozoan material from calcareous and dolomitic sandstone beds of the Whitehorse formation furnish basis for this discussion. The specimens were obtained from the Whitehorse Spring and Woodward localities in northwestern Oklahoma (localities 1 and 2) and from the Dozier lens in Collingsworth, Hall, and Eddy counties, northwestern Texas (localities 5, 7, 8, 9, and 10). They were gathered chiefly by Norman D. Newell, but a few, loaned from Peabody Museum, Yale University, were collected by Robert Roth. There are about 80 specimens, some consisting of numerous small fragments of zoaria on a rock fragment or embedded in it.

NATURE OF THE MATERIAL

Only cursory examination is necessary to show that all the fossil bryozoans obtained from the Whitehorse sandstone are ramose forms. A few examples that seem to be different in spreading outward as much as 25 by 25 mm., like incrusting growths, are merely the basal expansions of ramose zoaria. Close study leads to the conclusion that only one species of bryozoans is represented. Careful search at localities where the best preserved material occurs may yield additional data, but there is now no ground for separation of the specimens either on basis of external form and surface characters of the colonies, or of determinable internal structure. The observed features indicate a new species of *Lioclema*, which is named *L. dozierense*.

Some of the observed specimens consist of small fragments which may represent branches broken from a larger colony. Numerous examples of branching colonies measuring 25 to 50 mm. in one direction with attached branches reaching 10 to 20 mm. obliquely outward from the long dimension were seen. As observed by Newell in the introductory discussion, there can be no reasonable doubt that these fossils were not transported any great distance before burial; most of them were surrounded by sediments and changed to fossils exactly in the place where they grew, as indicated both by the preservation of the surface features on some specimens and by the absence of wear or breakage of branches in most specimens.

SYSTEMATIC DESCRIPTION

Phylum BRYOZOA Ehrenberg

Class TREPOSTOMATA Ulrich

Family BATOSTOMELLIDAE Ulrich

Genus *Lioclema* Ulrich

Lioclema dozierense Moore, n. sp.

(Text figures 11 a-c)

DESCRIPTION: Zoarium ramose, one or several branches rising from a basal expansion that may measure more than 25 mm. in diameter; branches ranging in

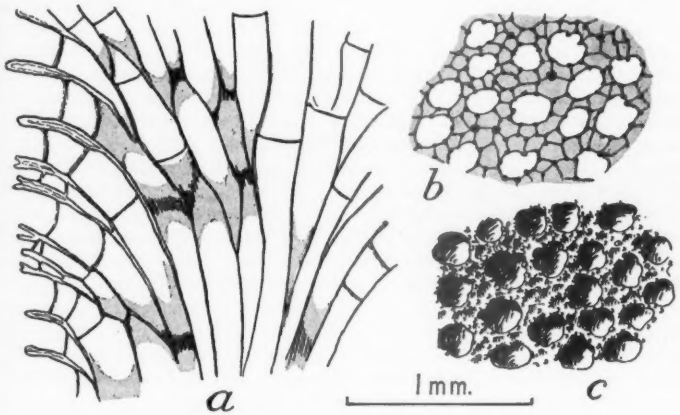

FIGURE 11.—*Lioclema dozierense Moore, n. sp.*

From Custer group, Upper Permian, of Oklahoma and Texas: *a*, longitudinal section of specimen from Motley County, Texas (Locality 10), × 30; *b*, tangential section of typical specimen from Collingsworth County, Texas (Locality 7), × 30; *c*, portion of surface of zoarium of holotype specimen from near Dozier, Texas (Locality 5), × 30, showing somewhat irregular outlines of zoöecial apertures, depressions representing mesopores, and the very numerous acanthopores.

diameter from 1 to 5 mm., average about 2 mm. The branches subdivide at short intervals, and some specimens appear to show coalescence of some contiguous branches. Secondary growth in laminar form around some branches are indicated in weathered specimens and are shown by longitudinal sections.

Zoöecial tubes are polygonal in cross section in the immature region where they are subparallel to the longitudinal axis of the branch and are separated from one another by thin walls; the tubes curve gradually outward, becoming more or less distinctly spread apart in the mature region where numerous mesopores and acanthopores are evident and the walls of the tubes are slightly thickened. There is no suggestion of a beadlike thickening of the walls, however, such as characterizes *Stenopora, Tabulipora,* and some other genera. The cross section of the mature portion of the zoöecia and the outline of the zoöecial apertures are approximately cir-

cular or oval, although in many cases indentations produce a lobate shape. The diameter of the apertures ranges from about 0.15 to 0.25 mm., and on the average there are about eight apertures in a space of 2 mm. Imperforate diaphragms that generally are a little concave toward the distal end of the tube divide the zoöecia into compartments; the diaphragms are 1 mm. or more apart in the immature part of the tubes but only 0.2 to 0.4 mm. apart near the surface.

Interspaces between the zoöecial apertures are ridged areas occupied by numerous small tubercles that mark the position of acanthopores, or they comprise both acanthopore-bearing ridged areas and angular depressions of polygonal outline that define mesopores. The mesopores are generally open to the surface. Their diameter ranges from about 0.04 mm. to as much as 0.2 mm. in exceptional cases, the average being about 0.08 mm. There is some variation in the abundance of mesopores in different specimens and different parts of the same specimen; the basal expansions appear to have somewhat fewer mesopores than the branches, where at least a single row of these minute tubes occurs between zoöecia as seen in tangential sections. No segregations of mesopores in the form of maculae or monticules are found on most of the branches, although there is a suggestion of low monticules on some specimens; a wax squeeze of the mold of a basal expansion, about 25 mm. in diameter, shows a regular pattern of very low but fairly distinct monticules composed of mesopores, each monticule about 0.2 mm. in diameter and the spaces between them such that four monticules and four interspaces occur in 6 mm.; the basal expansion mentioned contains the bottom portions of eight branches. One specimen consisting of a forked branch, 2 mm. in diameter, shows regularly spaced very narrow ridge-like monticules trending at right angles to the axis of the branch; they are spaced so that five monticules and interspaces occur in 5 mm.

Numerous diaphragms occur in the mesopores, some rather indistinct. The acanthopores range in diameter from 0.015 to 0.035 mm., the largest ones occurring generally midway between zoöecial apertures and the smaller ones in the walls of the zoöecial tubes and at angles between the mesopores. The acanthopores are not strongly produced externally, as in some species of *Lioclema*.

Discussion: Absence of a moniliform wall structure in the bryozoans here described removes them from consideration as belonging to such genera as *Stenopora* and *Tabulipora*. The observed structural features conform generally to those of *Batostomella* except that mesopores are more abundant and angular in outline than in that genus; the thickness of the zoöecial walls in the mature region is less marked. *Lioclema* is differentiated from *Batostomella* chiefly on the characters just mentioned and on the tendency toward indentations of the zoöecial apertures. This last feature is observed in the Custer bryozoans, and, because the abundance of mesopores and acanthopores combined with structure of the zoöecial tubes conforms to definition of *Lioclema*, generic assignment can be made without hesitation.

Among described species of *Lioclema*, mostly from Mississippian rocks, there is need for comparison only with *L. hirsutum* Moore, from the Graham formation of Virgil age (upper Pennsylvanian), and *L. shumardi* Girty, from the Delaware Mountain and Capitan (Permian) formations; these two species have been reported only from localities in Texas. *L. hirsutum* is distinguished from *L. dozierense* by the slightly larger average size of the zoöecial apertures, their wider spacing, more abundant mesopores, and especially by the much more strongly elevated surface projections of the acanthopores; in addition, it may be noted that the mature region in branches of *L. hirsutum* are much more thickened and more sharply separated from the immature region than is observed in *L. dozierense*. Comparison

with the Capitan and Delaware Mountain species described by Girty is more significant. *L. shumardi* resembles the new species from the Whitehorse sandstone in the average size and form of the branching zoaria and in the average size and gentle curvature of the zoöecial tubes. The spacing of the zoöecia is distinctly closer in *L. dozierense,* with about eight apertures in 2 mm. instead of five, as in *L. shumardi;* the number of mesopores in a given space is correspondingly smaller on the average in the Whitehorse species, although this is partly offset by the somewhat smaller size of mesopores in the latter. Judging from figures given by Girty, the diaphragms in the zoöecial tubes of *L. shumardi* are notably fewer and more widely spaced than in *L. dozierense;* it also appears that the number of acanthopores in a given area is much smaller in the Capitan-Delaware Mountain form than in that from the Whitehorse. Girty does not mention maculae or monticules in his description of *L. shumardi,* and no figures of the surface of a zoarium belonging to this species are given; the significance of maculae as a specific character of *L. dozierense* is not well established, however, and comparison cannot be made satisfactorily on this basis.

Evidence of the age of the Whitehorse beds, insofar as indicated by the bryozoans that have been collected, cannot be considered very conclusive. The fact that only a single species has been recognized in the Whitehorse material provides a narrow foundation indeed for comparisons based on this element of the fauna. Certainly the affinities of the bryozoans are with Paleozoic rather than younger representatives of this phylum, and this points to an assignment of the Whitehorse sandstone to the Permian. No satisfactory grounds for judgment concerning precise position of the strata containing *Lioclema dozierense* with reference to other Permian deposits are offered, for it is apparent that the distinctions observed between this species and *L. shumardi* may reflect either a difference in age or the effects of contrasting environments and perhaps geographic separation among approximately contemporaneous marine organisms.

Occurrence: Whitehorse formation, northwestern Oklahoma (locations 1 and 2); Dozier lens of the White horse formation, near Dozier (location 5), and adjacent places farther south in Collingsworth, Hall, and Eddy counties, northwestern Texas (locations 7-10).

Types: Holotype, University of Kansas collection, no. 30, 671, from location 5, near Dozier, Texas; paratypes include other determinable specimens from this and the remaining lots.

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Explanation of Plates

Plate 1

PELECYPODS FROM THE WHITEHORSE SANDSTONE

Figures 1-6. *Schizodus oklahomensis* Beede (p. 291).

(1) Artificial cast of left valve showing lack of rear cardinal tooth, Dozier lens, dolomite facies, locality 9; hypotype 20,804, Geol. Mus., Univ. Wis. (2) Cast of a smaller left valve, showing dentition characteristic of *Schizodus*, same horizon, locality 7-a; hypotype 20,805, Geol. Mus., Univ. Wis. (3) Cast of robust right valve, showing dentition, same horizon and locality as Figure 1; hypotype 20,806, Geol. Mus., Univ. Wis. (4) Internal mold, left valve, showing anterior adductor scar and pallial line, Dozier lens, dolomite facies, locality 7-a; hypotype 16,334, Peabody Mus., Yale Univ. (5) Holotype, right valve, abnormally long relative to height; Whitehorse Springs lens, locality 1; holotype 170, Geol. Mus., Univ. Kansas. (6) Artificial cast of large right valve, Dozier lens, sandstone facies, locality 9; hypotype 20,807, Geol. Mus., Univ. Wis.

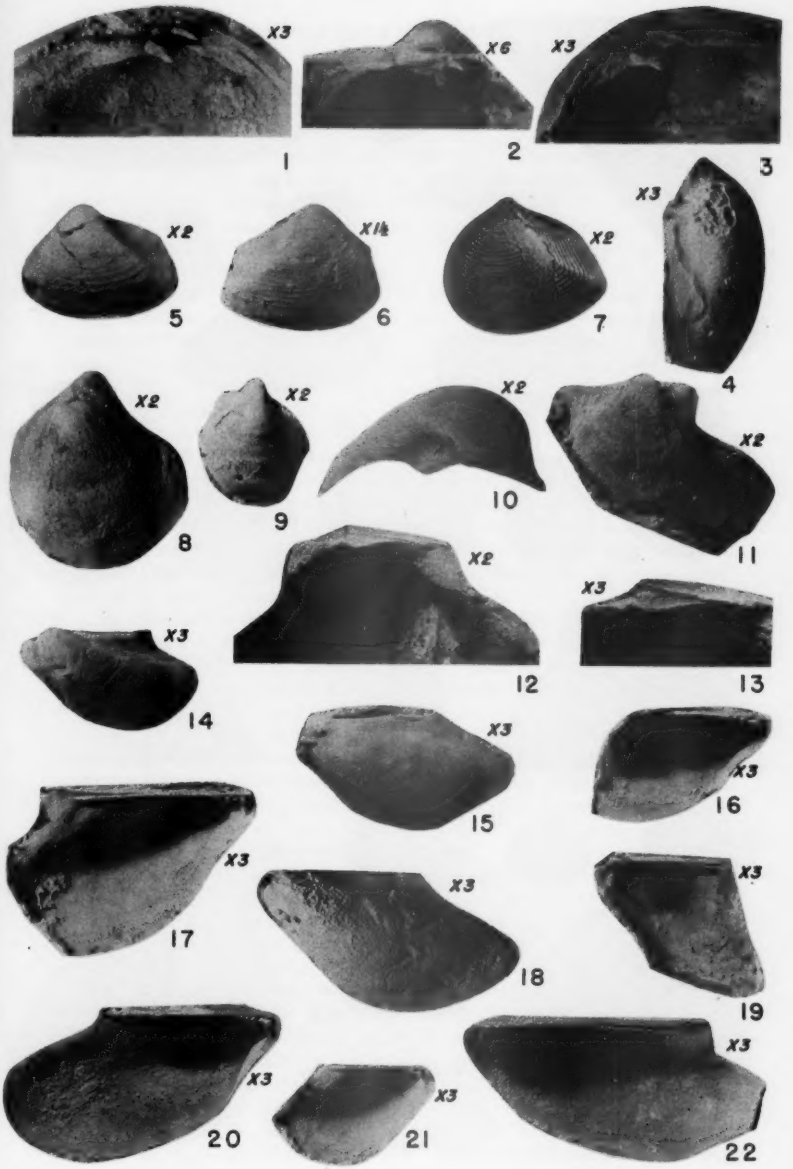
Figure 7. *Schizodus praecox* (Waagen). After Waagen. Described as *Myophoria praecox*, this species from uppermost Permian of Salt Range of India figured for comparison with *Schizodus oklahomensis*.

Figures 8-13. *Gryphellina sellardsi* (Beede) (p. 289).

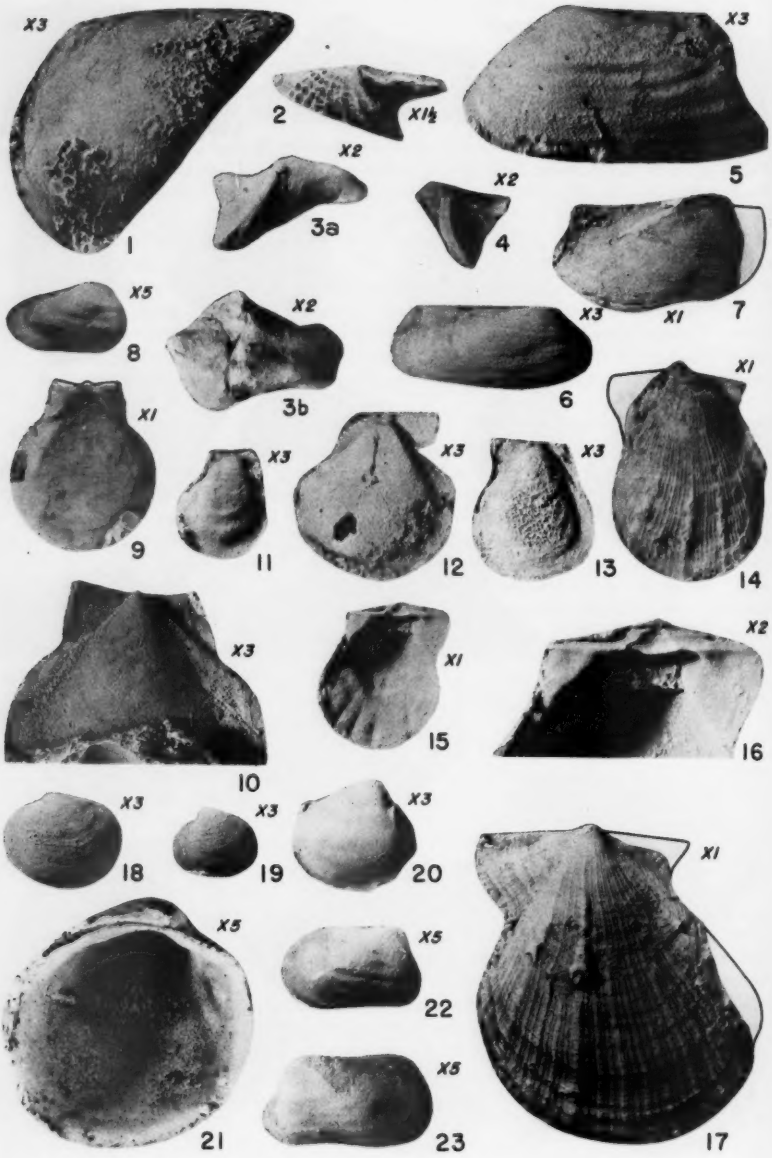
(8) Internal mold of large right valve, Whitehorse Springs lens, locality 1; hypotype 20,808, Geol. Mus., Univ. Wis. (9) Smaller internal mold of right valve, Dozier lens, dolomite facies, locality 7-a; hypotype 16,335, Peabody Mus., Yale Univ. (10-11) Artificial cast of external mold of robust right valve, showing ornamentation and form of auricles, Dozier lens, dolomite facies, locality 7-a; hypotype 16,336, Peabody Mus., Yale Univ. (12-13) Artificial cast of a right valve, showing hinge plate and oblique resilifer comparable to that of *Lima* or some aviculopectens; small projection may be hinge tooth of sort seen in some species of *Pteria*. Whitehorse Springs lens, locality 1; hypotype 20,809, Geol. Mus., Univ. Wis.

Figures 14-22. *Dozierella gouldii* (Beede) (p. 284).

(14) Relatively small left valve, Whitehorse Springs lens, locality 1; hypotype 193, Geol. Mus., Univ. Kansas. (15) Internal mold of left valve, showing anterior adductor scar and pallial line, and scar of pedal retractor near apex of beak, Dozier lens, dolomite facies, locality 7-a; hypotype 16,337, Peabody Mus., Yale Univ. (16) Artificial cast of left valve showing cardinal teeth, Dozier lens, dolomite facies, locality 9; hypotype 20,810, Geol. Mus., Univ. Wis. (17) Artificial cast of left valve, showing well the hinge characters, same horizon and locality as preceding; hypotype 20,811, Geol. Mus., Univ. Wis. (18) Internal mold of left valve showing posterior muscle scar; pallial line not visible, same horizon as preceding, locality 7-d; hypotype 16,338, Peabody Mus., Yale Univ. (19) Artificial cast of right valve, Dozier lens, dolomite facies, locality 9; hypotype 20,812, Geol. Mus., Univ. Wis. (20) Artificial cast of left valve, same horizon and locality as preceding; hypotype 20,813, Geol. Mus., Univ. Wis. (21) Artificial cast of left valve, juvenile, same horizon and locality as preceding; hypotype 20,814, Geol. Mus., Univ. Wis. (22) Artificial cast of right valve, same horizon and locality; hypotype 20,815, Univ. Wis.



PELECYPODS FROM THE WHITEHORSE SANDSTONE



PELECYPODS FROM THE WHITEHORSE SANDSTONE

PLATE 2

PELECYPODS FROM THE WHITEHORSE SANDSTONE

Figure 1. *Myalina* sp. (p. 286).

Right valve, artificial cast, from Dozier lens, dolomite facies, locality 7-d; hypotype 16,326, Peabody Mus., Yale Univ.

Figures 2-4. *Conocardium oklahomense* Beede (p. 286).

(2) Right valve, artificial cast, from Whitehorse Springs lens, sandstone facies, locality 1; hypotype 163-E, Geol. Mus., Univ. Kansas. (3a-b) Internal mold, from Whitehorse Springs lens, sandstone facies, locality 1; hypotype 163-B, Geol. Mus., Univ. Kansas. (4) Oblique anterior view of right valve, showing fine costae, from Whitehorse Springs lens, sandstone facies, locality 1; hypotype 163-F, Geol. Mus., Univ. Kansas.

Figures 5, 6. *Allorisma rothi* Newell, n. sp. (p. 296).

(5) Fragmentary large left valve, from Dozier lens, dolomite facies, locality 9; paratype 20,795, Geol. Mus., Univ. Wis. (6) Medium-sized right valve, from Dozier lens, dolomite facies, locality 9; holotype 20,796, Geol. Mus., Univ. Wis.

Figure 7. *Parallelodon* sp. (p. 288).

Fragmentary right valve, artificial cast, from Dozier lens, dolomite facies, locality 5; hypotype 20,797, Geol. Mus., Univ. Wis.

Figures 8, 22, 23. *Allorisma? albequus* Beede (p. 296).

(8) Right valve, internal mold, probably somewhat pathologic individual, from Dozier lens, locality 9; hypotype 20,798, Geol. Mus., Univ. Wis. (22) Internal mold of normal right valve, same horizon, locality 7-a; hypotype 16,327, Peabody Mus., Yale Univ. (23) Internal mold of relatively robust left valve, designated here as lectotype, same horizon at locality 6; lectotype 173-C, Geol. Mus., Univ. Kansas.

Figures 9, 10. *Pernopecten symmetricus* Newell, n. sp. (p. 294).

(9) Artificial cast of internal mold of left valve, Dozier lens, locality 6; holotype 16,328, Peabody Mus., Yale Univ. (10) Artificial cast of external mold of left valve, same horizon, locality 9; paratype 20,799, Geol. Mus., Univ. Wis.

Figures 11-13. *Pseudamusium* sp. (p. 295).

(11) Internal mold of small right valve, Dozier lens, dolomite facies, locality 7-a; hypotype 16,329, Peabody Mus., Yale Univ. (12) Internal mold of more mature right valve, same horizon, locality 6; hypotype 16,330, Peabody Mus. Yale Univ. (13) Internal mold of left valve, same horizon, locality 7-d; hypotype 16,331, Peabody Mus., Yale Univ.

Figures 14-17. *Aviculopecten vancleeti* Beede (p. 293).

(14) Left valve, one of Beede's meotypes, showing characteristic posterior sulcus on body of shell, Whitehorse Springs lens, locality 1; neotype 172-B, Geol. Mus., Univ. Kansas. (15-16) Artificial cast of internal mold of left valve, showing hinge plate and resilifer characteristic of *Aviculopecten*, Dozier lens, sandstone facies, locality 6; hypotype 16,332, Peabody Mus., Yale Univ. (17) Artificial cast of external mold of extraordinarily robust left valve, Dozier lens, dolomite facies, locality 5; hypotype 20,800, Geol. Mus., Univ. Wis.

Figures 18-21. *Edmondia rotunda* Beede (p. 281).

(18) Artificial cast of relatively robust left valve, Dozier lens, dolomite facies, locality 5; hypotype 20,801, Geol. Mus., Univ. Wis. (19) Artificial cast of smaller external mold, same horizon, locality 7-a; hypotype 16,333, Peabody Mus., Yale Univ. (20) Internal mold of right valve, same horizon, locality 5; hypotype 20,802, Geol. Mus., Univ. Wis. (21) Artificial cast of robust left valve, showing hinge characters and deep imprint of anterior muscle, same horizon and locality as preceding; hypotype 20,803, Geol. Mus., Univ. Wis.

PLATE 3

PELECYPODS FROM THE WHITEHORSE SANDSTONE

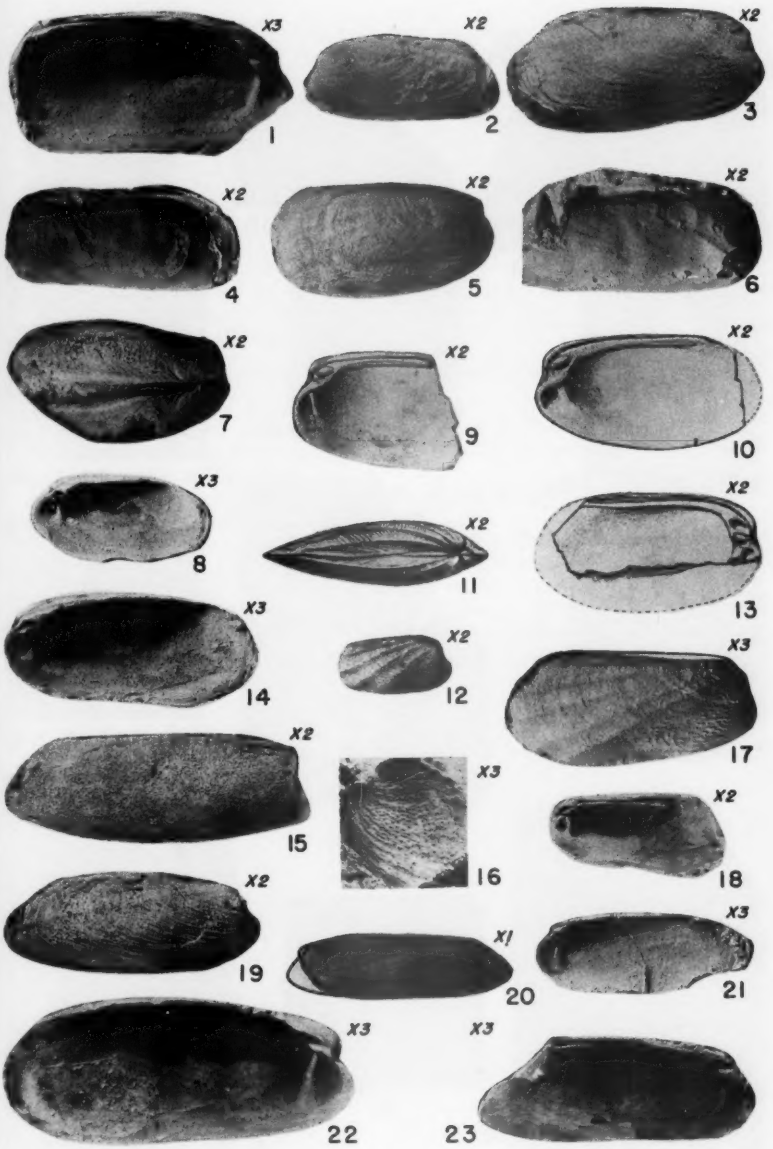
Figures 1, 4-8, 14, 16-18. *Pleurophorus albequus* Beede (p. 298).

(1) Artificial cast of fragmentary left valve, showing cardinal dentition; posterior lateral largely broken away, Dozier lens, dolomite facies, locality 9; hypotype 20,816, Geol. Mus., Univ. Wis. (4) Posterior part of internal mold of left valve, showing faint trace of posterior adductor, and pallial line, Dozier lens, dolomite facies, locality 5; hypotype 20,817, Geol. Mus., Univ. Wis. (5) Artificial cast of right valve, posterior margin nearly entire, Dozier lens, dolomite facies, locality 7-d; hypotype 16,339, Peabody Mus., Yale Univ. (6) Posterior part of internal mold of left valve, showing adductor scar and part of pallial line, Dozier lens, dolomite facies, locality 7-a; hypotype 16,340, Peabody Mus., Yale Univ. (7) Artificial cast of fragmentary bivalved individual, showing position and size of ligament, Dozier lens, dolomite facies, locality 5; hypotype 20,818, Geol. Mus., Univ. Wis. (8) Artificial cast of small right valve, showing hinge characters, Dozier lens, dolomite facies, locality 9; hypotype 20,819, Geol. Mus., Univ. Wis. (14) More mature individual, same horizon and locality as preceding; hypotype 20,820, Geol. Mus., Univ. Wis. (16) Fragment of external mold of right valve, showing papillate surface, same locality and horizon as preceding; hypotype 20,821, Geol. Mus., Univ. Wis. (17) Artificial cast of imperfect right valve, Dozier lens, sandstone facies, locality 6; selected here as lectotype, 174-A, Geol. Mus., Univ. Kansas. (18) Artificial cast of right valve, showing transposed hinge, nearly unique in Paleozoic pelecypods, with dentition similar to that characteristic of left valves, Dozier lens, dolomite facies, locality 9; hypotype 20,822, Geol. Mus., Univ. Wis.

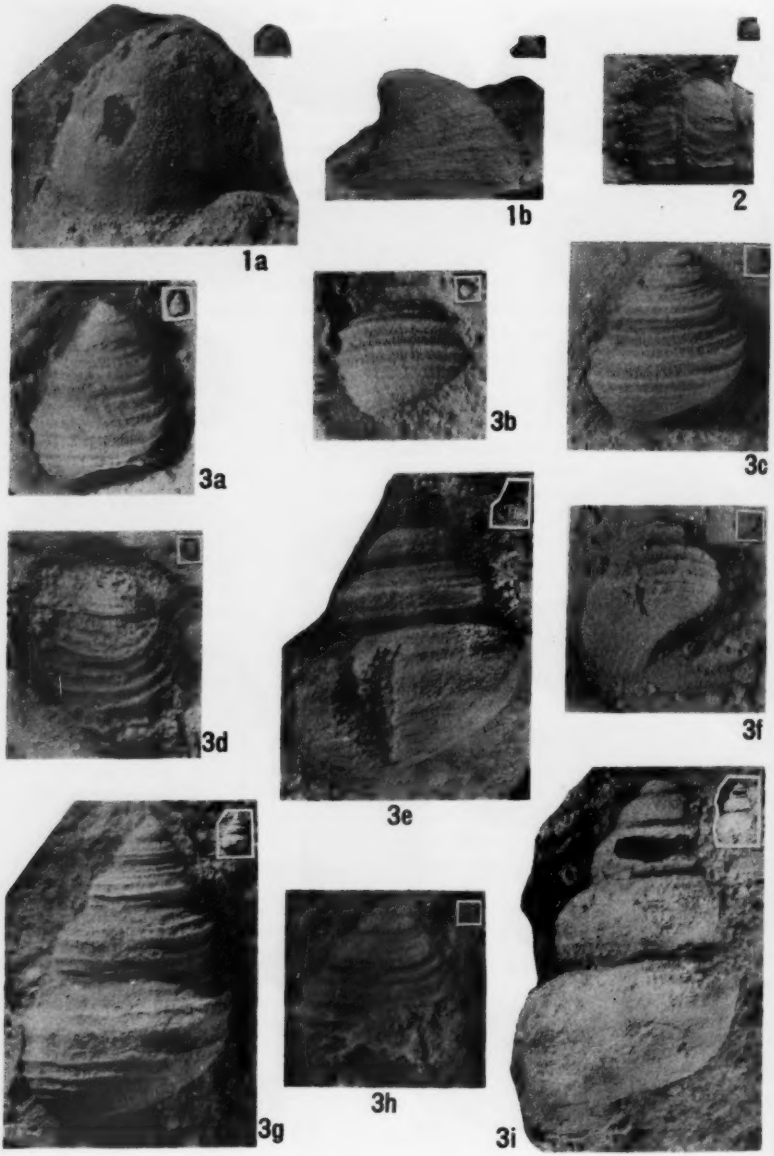
Figures 2, 3, 15, 19-23. *Pleurophorus albequus longus* Beede (p. 300).

(2, 3) Artificial casts of left and right valves, respectively, from Dozier lens, dolomite facies, locality 9; hypotypes 20,823-20,824, Geol. Mus., Univ. Wis. (15) Poorly preserved internal mold of right valve, Whitehorse Springs lens, locality 1; holotype, 175, Geol. Mus., Univ. Kansas. (19) Artificial cast of a right valve, Dozier lens, dolomite facies, locality 7-d; hypotype 16,341, Peabody Mus., Yale Univ. (20) Artificial cast of large left valve, Dozier lens, sandstone facies, locality 9; hypotype 20,825, Geol. Mus., Univ. Wis. (21) Artificial cast of right valve, showing more delicate dentition than in *Pleurophorus albequus,* same locality and horizon as preceding; hypotype 20,826, Geol. Mus., Univ. Wis. (22) Imperfect cast of left valve; postero-dorsal part of shell, including lateral tooth, is missing, Dozier lens, dolomite facies, locality 7-a; hypotype 20,827, Geol. Mus., Univ. Wis. (23) Cast of incomplete left valve, Dozier lens, dolomite facies, locality 9; hypotype 20,828, Geol. Mus., Univ. Wis.

Figures 9-13. *Pleurophorus costatus* (Brown). After Böhm. Genotype of *Pleurophorus,* from Magnesian limestone of England, introduced here for comparison.



PELECYPODS FROM THE WHITEHORSE SANDSTONE



GASTROPODS FROM THE WHITEHORSE SANDSTONE

PLATE 4

GASTROPODS FROM THE WHITEHORSE SANDSTONE

Figures 1 a-b. *Lepetopsis? haworthi* (Beede) (p. 302).

(1a) Holotype, left side view, ×8; holotype 188-C, Geol. Mus., Univ. Kansas.

(1b) Wax squeeze from hypotype, ×6; No. 15,326, Peabody Mus., Yale Univ.

Fig. 2. *Bellerophon* sp. (p. 303).

Squeeze from only known specimen; No. 51,500, Princeton Univ.

Figures 3 a-i. *Baylea capertoni* (Beede) (p. 303).

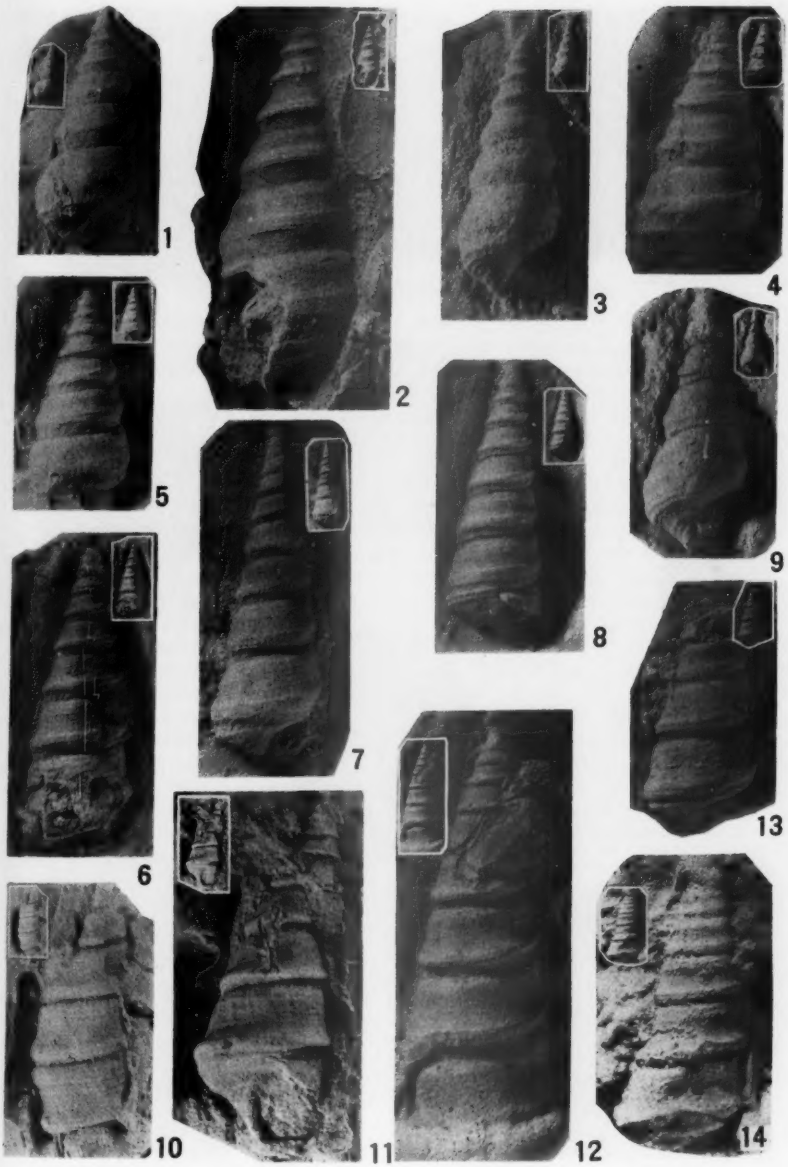
(3a) Wax squeeze from hypotype, ×8; No. 15,327, Peabody Mus., Yale Univ. (3b) Wax squeeze from hypotype, ×8; No. 15,328, Peabody Mus., Yale Univ. (3c) Wax squeeze from hypotype, ×8; No. 51,483, Princeton Univ. (3d) Wax squeeze from hypotype, ×10; No. 51,484, Princeton Univ. This young individual shows selenizone well. (3e) One of Beede's paratypes, ×8; No. 177-B, Geol. Mus., Univ. Kansas, a steinkern. (3f) Wax squeeze from hypotype, ×8; No. 51,485, Princeton Univ. shows base. (3g) Wax squeeze from lectotype, ×8; No. 177-E, Geol. Mus., Univ. Kansas. Only original specimen that shows selenizone clearly. (3i) Lectotype of *Pleurotomaria agnostica* Beede, ×6; No. 178-A, Geol. Mus., Univ. Kansas. Steinkern. Name *P. agnostica* referred to synonymy of *B. capertoni*.

PLATE 5

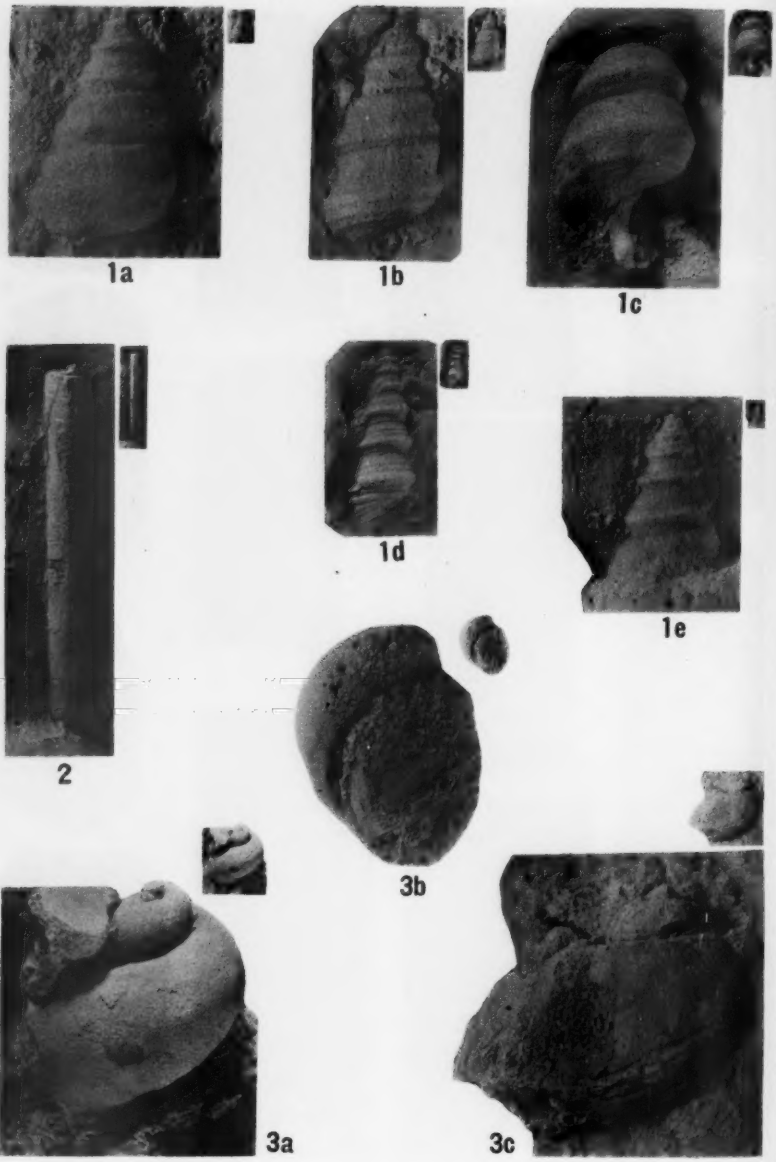
GASTROPODS FROM THE WHITEHORSE SANDSTONE

Figures 1-14. *Murchisonia gouldii* Beede (p. 306).

(1) Wax squeeze from hypotype, ×4; No. 51,486, Princeton Univ. Note apparent outline of earlier slit shown by growth lines. (2) Wax squeeze from lectotype, ×6; No. 183-A, Geol. Mus., Univ. Kansas. Note revolving lines on selenizone. (3) Wax squeeze from hypotype, ×4; No. 15,329, Peabody Mus., Yale Univ. (4) Wax squeeze from hypotype, ×4; No. 15,330, Peabody Mus., Yale Univ. (5) Wax squeeze from hypotype, ×4; No. 51,487, Princeton Univ. Note faint crenulations on selenizone. (6) Wax squeeze from hypotype, ×4; No. 51,488, Princeton Univ. (7) Wax squeeze from hypotype, ×4; No. 51,489, Princeton Univ. Note relatively strong revolving ornamentation and crenulations on selenizone. (8) Wax squeeze from hypotype, ×4; No. 51,490, Princeton Univ. (9) Wax squeeze from hypotype, ×4; No. 51,491, Princeton Univ. Note moderately high selenizone, strong revolving ornamentation on base and none on sides. (10) Wax squeeze from hypotype, ×4; No. 15,331, Peabody Mus., Yale Univ. Note abundant revolving lirae. (11) Wax squeeze from hypotype, ×4; No. 15,332, Peabody Mus., Yale Univ. Note fine revolving lirae and columellar lip. (12) Wax squeeze from hypotype, ×4; No. 15,333, Peabody Mus., Yale Univ. (13) Wax squeeze from hypotype, ×4; No. 15,334, Peabody Mus., Yale Univ. (14) Wax squeeze from lectotype of *Orthonema? texana* Beede; No. 186-E, Geol. Mus., Univ. Kansas. The name *O.? texana* is referred to synonymy of *M. gouldii*.



GASTROPODS FROM THE WHITEHORSE SANDSTONE



GASTROPODS FROM THE WHITEHORSE SANDSTONE

PLATE 6

GASTROPODS FROM THE WHITEHORSE SANDSTONE

Figures 1 a-e. *Murchisonia gouldii* Beede (p. 306).

(1a) Wax squeeze from holotype of *Murchisonia collingsworthensis* Beede, ×8; No. 182, Geol. Mus., Univ. Kansas. Name *M. collingsworthensis* is referred to synonymy of *M. gouldii*. (1b) Wax squeeze from paratype of *Orthonema? texana* Beede, ×4; No. 186-C, Geol. Mus., Univ. Kansas. Name *O.? texana* is referred to synonymy of *M. gouldii*. (1c) Wax squeeze from hypotype, ×4; No. 51,492, Princeton Univ. Note form of columellar lip. Revolving ornamentation relatively weak. (1d) Wax squeeze from hypotype, ×4; No. 15,335, Peabody Mus., Yale Univ. Young individual with low selenizone lying on lower side of periphery of sharply angular whorl, with strongly developed revolving ornamentation and very narrow pleural angle. (1e) Wax squeeze from hypotype, ×8; No. 51,493, Princeton Univ. Young individual with selenizone lying on lower side of periphery of sharply angular whorl, but with weakly developed revolving ornamentation and very wide pleural angle.

Figure 2. *Plagioglypta girtyi* Knight, n. sp. (p. 315).

Wax squeeze from holotype, ×4; No. 15,336, Peabody Mus., Yale Univ.

Figures 3 a-c. *Naticopsis transversus* (Beede) (p. 312).

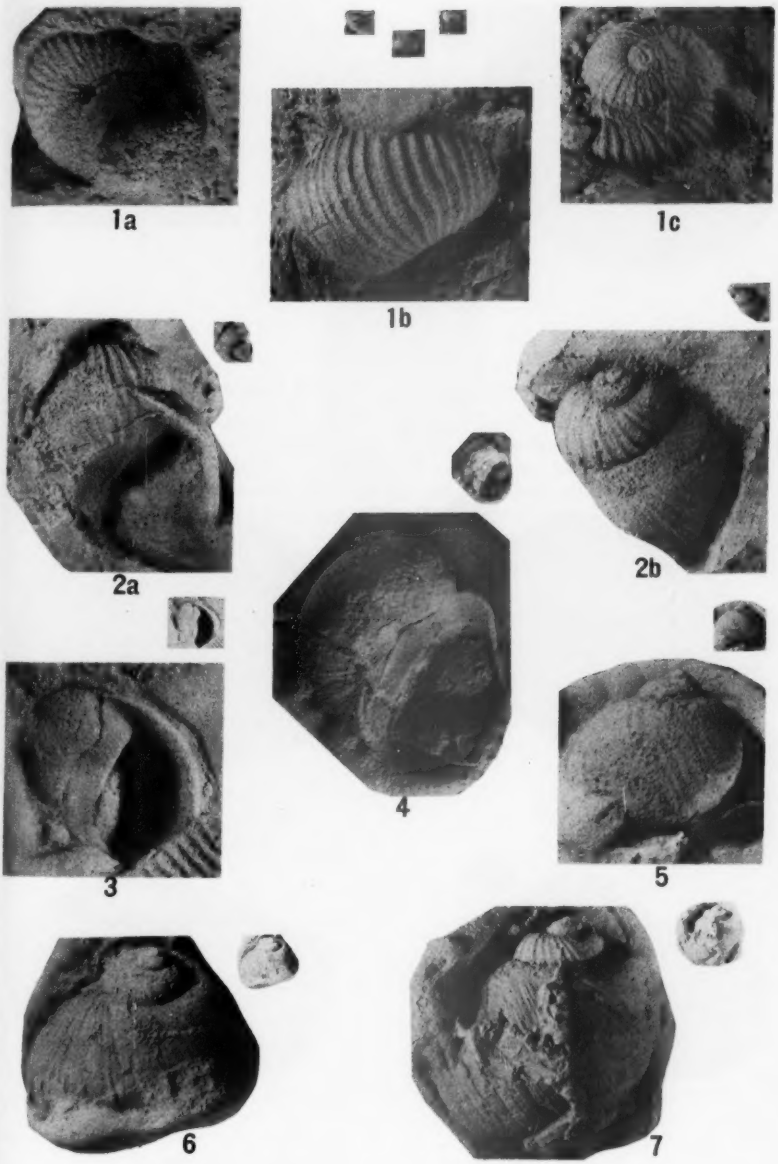
(3a) Hypotype, ×4; No. 15,337, Peabody Mus., Yale Univ. Clear, unmasked steinkern shows aspect of specimens of species in this condition. (3b) Paratype of *Strophostylus permianus* Beede; No. 190-B, Geol. Mus., Univ. Kansas. Steinkern. Name *S. permianus* placed in synonymy of *N. transversus*. (3c) Lectotype of *Strophostylus permianus* Beede; No. 190-A, Geol. Mus., Univ. Kansas. Specimen is a steinkern. Name is synonym of *N. transversus*.

PLATE 7

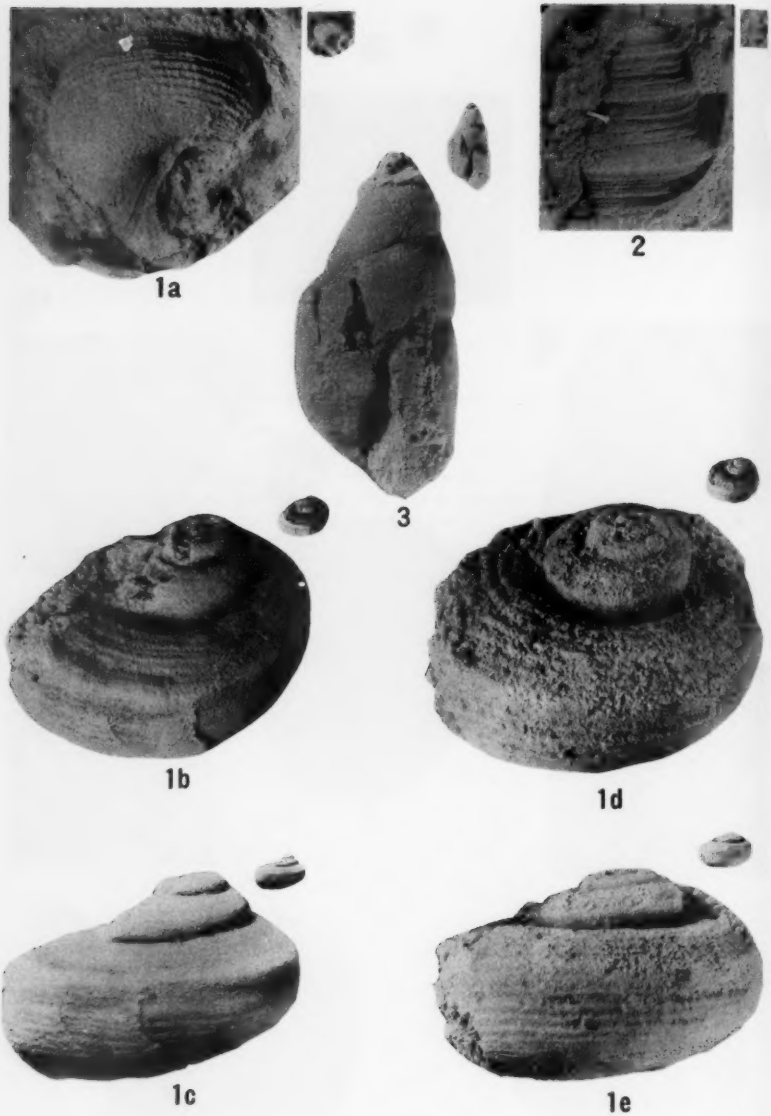
GASTROPODS FROM THE WHITEHORSE SANDSTONE

Figures 1-7. *Naticopsis transversus* (Beede) (p. 312).

(1 a-c) Wax squeezes from three parts of holotype, ×8; No. 191 A-C, Geol. Mus., Univ. Kansas. Note that this specimen, the holotype of *Naticella transversa* Beede, corresponds in size and ornamentation with earlier whorls of specimens represented in Figures 2 a-b and 7. *"Naticella transversa"* Beede must be young example of *"Strophostylus permianus"* Beede. They are therefore united under the name employed above. (2 a-b) Wax squeezes from hypotype, ×6; No. 51,494, Princeton Univ. Note remarks above. (3) Wax squeeze from hypotype, ×4; No. 51,495, Princeton Univ. This squeeze shows apertural characters faithfully. (4) Wax squeeze from hypotype, ×4; No. 15,338, Peabody Mus., Yale Univ. Excellently preserved aperture. (5) Wax squeeze from hypotype, ×4; No. 15,339, Peabody Mus., Yale Univ. (6) Wax squeeze from hypotype, ×4; No. 15,339, Peabody Mus., Yale Univ. (7) Wax squeeze from hypotype, ×4; No. 15,340, Peabody Mus., Yale Univ.



GASTROPODS FROM THE WHITEHORSE SANDSTONE



GASTROPODS FROM THE WHITEHORSE SANDSTONE

PLATE 8

GASTROPODS FROM THE WHITEHORSE SANDSTONE

Figures 1 a-e. *Cyclites depressus* (Beede) (p. 311).

(1 a-c) Holotype of *Pleurotomaria multilineata* Girty, ×6; Carboniferous collections of U. S. G. S. (1a) Wax squeeze from external mold of base shows characters of columellar lip, base, and external ornamentation. Note gently oblique but straight lines of growth. (1 b-c) Two views of steinkern. Name *P. multilineata* is placed in synonymy of prior trivial name *C. depressus*. (1 d-e) Holotype of *Worthenopsis? depressa* Beede, ×6; No. 179, Geol. Mus., Univ. Kansas. Note how closely this steinkern compares with that of type of *P. multilineata*. Differences are chiefly those caused by differences in matrix.

Figure 2. *Worthenia beedei* Knight, n. sp. (p. 305).

Wax squeeze from holotype, ×6; No. 15,341, Peabody Mus., Yale Univ.

Figure 3. *Girtyspira? alvaensis* (Beede) (p. 313).

Holotype, ×4; No. 187, Geol. Mus., Univ. Kansas. This specimen, distorted steinkern, is too poorly preserved to permit certain generic reference, and no other specimen remotely resembling it has yet been found in the same beds.

PLATE 9

GASTROPODS FROM THE WHITEHORSE SANDSTONE

Figures 1 a-d. *Taosia dozierensis* (Beede) (p. 310).

(1a) Wax squeeze from holotype, ×8; No. k85, Geol. Mus., Univ. Kansas. Note faint transverse undulations and faint trace of selenizone. (1b) Wax squeeze from hypotype, ×4; No. 15,342, Peabody Mus., Yale Univ. Note transverse undulations and selenizone; both are more sharply preserved than on holotype. (1c) Wax squeeze from hypotype, ×6; No. 15,344, Peabody Mus., Yale Univ. This specimen shows well the characters of base and columellar lip.

Figures 2 a-c. *Streptacis permiana* (Beede) (p. 313).

(2a) Wax squeeze from hypotype, ×8; No. 15,345, Peabody Mus., Yale Univ. Lower half of growth line marking sinus in outer lip may be seen very faintly on next to last whorl. (2b) Wax squeeze from hypotype, ×6; No. 51,497, Princeton Univ. (2c) Wax squeeze from lectotype, ×15; No. 184-B, Geol. Mus., Univ. Kansas.

Figures 3 a-f. *Cyclobathmus haworthi* (Beede) (p. 314).

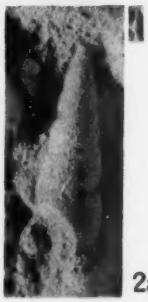
(3a) Lectotype, ×8; No. 181-C, Geol. Mus., Univ. Kansas. Steinkern which does not show external ornamentation well. (3b) Paratype, ×8; No. 181-B, Geol. Mus., Univ. Kansas. Another steinkern, as were all three of Beede's syntypes. (3c) Wax squeeze from hypotype, ×10; No. 51,498, Princeton Univ. Small individual showing earlier whorls. (3d) Wax squeeze from hypotype, ×10; No. 51,499, Princeton Univ. This specimen shows very well the base, columellar lip, and ornamentation. (3e) Wax squeeze from hypotype, ×10; No. 15,346, Peabody Mus., Yale Univ. This specimen shows ornamentation well. (3f) Wax squeeze from hypotype, ×10; No. 15,347, Peabody Mus., Yale Univ. This specimen, a fragment of a large individual, shows well the lines of growth. These lines of growth mark the form of the outer lip, a diagnostic character of the genus based on this species.

1a

1b

1c

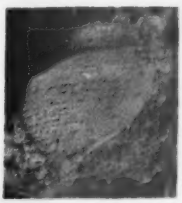
1d


2a

2b

2c

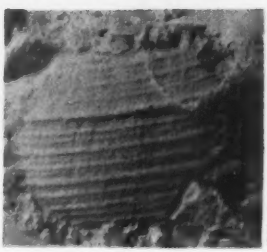
3a


3b

3c

3d

3e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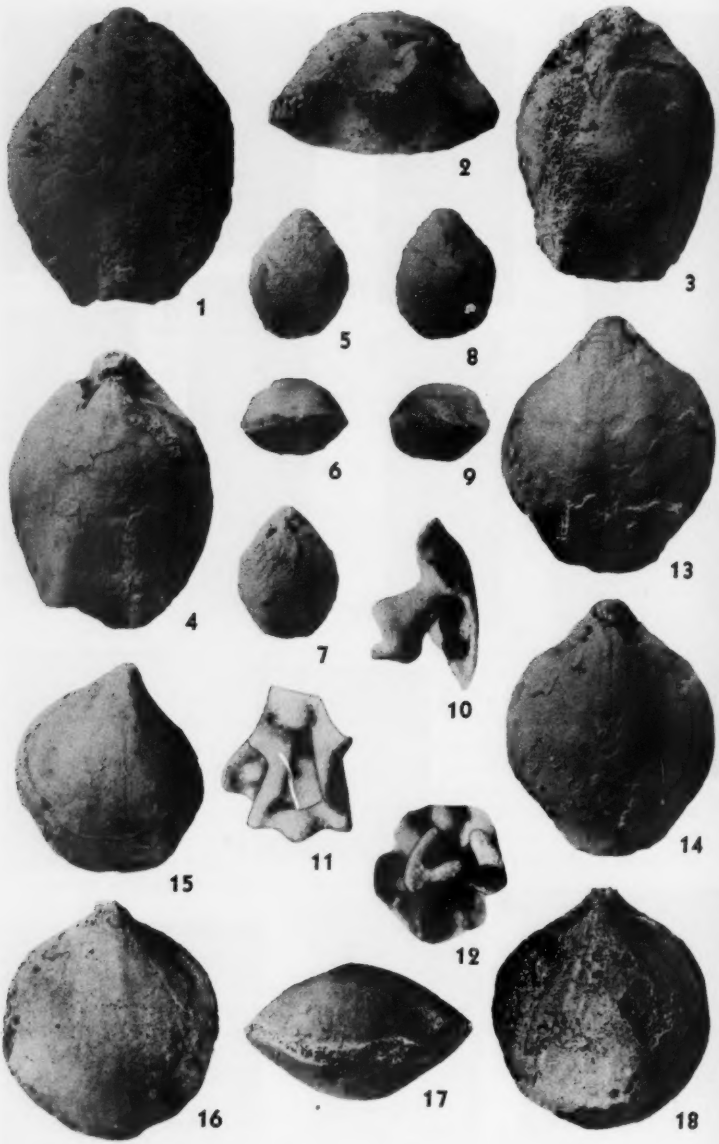
GASTROPODS FROM THE WHITEHORSE SANDSTONE



BRACHIOPODS FROM THE WHITEHORSE SANDSTONE

PLATE 10

BRACHIOPODS FROM THE WHITEHORSE SANDSTONE

Figures 1-4. *Dielasma schucherti* Beede (p. 316).

(1) Internal mold of large specimen, ×3, hypotype; No. 15,276, Peabody Mus., Yale Univ. (2) Anterior view of same specimen. (3) Internal mold of dorsal valve of neotype; No. 21,601, Geol. Mus., Univ. Kansas. (4) Internal mold of dorsal valve which bears enough shell to show growth lines; No. 15,277, Peabody Mus., Yale Univ. A hypotype.

Figures 5-12. *Pseudodielasma perplexa* Brill, n. gen. and n. sp. (p. 318).

(5-7) Ventral, anterior, and dorsal views of internal mold, ×3, holotype; No. 15,278, Peabody Mus., Yale Univ. (8, 9) Ventral and anterior views of internal molds, ×3, paratype; No. 21,602, Geol. Mus., Univ. Kansas. (10-12) Lateral, anterior, and ventral views of loop, ×10; No. 21,603, Geol. Mus., Univ. Kansas.

Figures 13, 14. *Composita mexicana* (Hall) (p. 318).

Ventral and dorsal views of internal mold, ×3; No. 15,280, Peabody Mus., Yale Univ.

Figures 15-18. *Composita subscircularis* Brill, n. sp. (p. 319).

(15) Ventral view of crushed specimen, ×3, showing lines of growth, paratype; No. 21,605, Geol. Mus., Univ. Kansas. (16-18) Ventral, anterior (ventral side up), and dorsal views of internal mold, holotype; No. 21,604, Geol. Mus., Univ. Kansas.